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DIMETHOXYMETHANE IN DIESEL FUEL: Chemical Characterization of Toxicologically Relevant Compounds from Diesel Emissions

INTERIM REPORT
TFLRF No. 358

by
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Under Contract to

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The objective of this study was to quantify engine-out emissions of potentially toxic compounds from a modern diesel engine operated with different fuels. Five diesel fuels were examined: a low-sulfur, low-aromatic hydrocracked fuel, the same low sulfur fuel containing 15% v/v dimethoxy methane, a Fischer-Tropsch fuel, a California reformulated fuel, and a EPA number 2 certification fuel. A DaimlerChrysler OM611 CIDI engine was controlled with a SwRI Rapid Prototyping Electronic Control system. The engine was operated over 5 speed-load modes. Each operating mode and fuel combination was run in triplicate. Thirty-three potentially toxic compounds were measured for each fuel and mode. An analysis of variance of the fuels showed that, in general, the 15% v/v dimethoxy methane fuel and the Fisher-Tropsch fuels had significantly lower emissions of measured compounds compared to the remaining fuels and were statistically indistinguishable from each other. The effect of pilot fuel injection on engine-out emissions was also determined. The pilot fuel injection was either turned off or turned on with engine control by either Location of Peak Pressure (LPP) of combustion or the original equipment manufacturer (OEM) calibration strategy. These three control strategies were compared over 2 speed-load modes run in triplicate. Thirty-three potentially toxic compounds were measured. In general, either pilot fuel injection strategy (LPP or OEM) produced higher emissions than with pilot injection turned off.

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EXECUTIVE SUMMARY

Objectives:

- Investigate the role of dimethoxy methane as an oxygenated diesel fuel additive on the engine-out exhaust emissions of potentially toxicologically relevant compounds.
- Determine the polycyclic aromatic hydrocarbon (PAH) content of organic solvent extracts of exhaust particulate matter; gaseous exhaust PAH; other toxic air pollutants collected from a diesel engine using various fuel compositions and engine operating conditions.

Approach:

- A DaimlerChrysler OM611 CIDI engine was used to determine the effect of diesel fuel type on toxicologically relevant compounds from engine-out exhaust emissions.
- The engine was controlled by a SwRI Rapid Prototyping Electronic Control System (RPECS).
- The test matrix included 5 fuels (including one oxygenate blend) operated over 5 speed/load points.
- Each speed/load point was devised to hold Location of Peak Pressure (LPP) at 7°ATDC, while maintaining cylinder balance within 5 % of the Indicated Mean Effective Pressure (IMEP), with pilot fuel injection disabled.
- Two of the speed/load points were operated at two different pilot fuel injection strategies. One pilot strategy used the stock controller, while the other was to include pilot fuel injection while maintaining the Location of Peak Pressure at a constant.
- Four toxic air pollutant exhaust emissions were measured.
- Eleven gaseous PAH compounds were measured.
- Seventeen PAH compounds were determined from the soluble organic fraction of the exhaust particulate matter.

Accomplishments:

- All fuel tests were completed in triplicate for five modes, pilot injections off, LPP operation. Evaluation of pilot fuel injection effects for all fuels were completed in triplicate for two modes and two pilot fuel injection strategies.
- Statistically significant fuel effects on exhaust emissions were identified.
- Oxygenate-containing fuel and Fischer-Tropsch fuel produced the lowest overall toxic air pollutant and PAH exhaust emissions.

Future Directions:

In a follow-on phase, similar investigations will be conducted using an engine with exhaust emission control devices.

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SYMBOLS AND ABBREVIATIONS

ADMM15	Blend of 15%v DMM in ALS fuel
ALS	Alternative Low Sulfur
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
ATDC	After Top Dead Center
bhp	Brake Horse Power
BMEP	Brake Mean Effective Pressure
BSFC	Brake Specific Fuel Consumption
CARB	California Reference Fuel
CIDI	Compression Ignition, Direct Injection
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COTR	Contracting Officer's Technical Representative
DF-2	EPA Certification Grade Diesel Fuel
DMM	Dimethoxymethane
DNPH	Dinitrophenylhydrazine
DOE	Department of Energy
DPF	Diesel Particulate Filter
EGR	Exhaust Gas Recirculation
FT-100	Neat Fischer-Tropsch Fuel
HC	Hydrocarbon
IMEP	Indicated Mean Effective Pressure
LPP	Location of Peak Pressure
NOx	Nitrogen Oxides
PAH	Polycyclic aromatic hydrocarbon
PM	Particulate Matter
PNGV	Partnership for a New Generation of Vehicles
RPECS	SwRI Rapid Prototyping Electronic Control System
RPM	Revolutions per Minute
SOF	Soluble Organic Fraction
SwRI	Southwest Research Institute
TARDEC	Tank-Automotive Research Development and Engineering Center
TFLRF	U.S. Army TARDEC Fuels and Lubricants Research Facility

1.0 INTRODUCTION

1.1 Background

This project exists as follow-on work to Phase I and Phase II emissions research utilizing a DaimlerChrysler OM611 diesel engine. The Phase I testing was designed to evaluate the potential benefits of several alternative diesel fuels without making any adjustments to the engine control system[1]. The objective of the second phase of work was to optimize the OM611 engine for a subset of the seven fuels that were tested in Phase I, as well as the fuels recommended by the Auto/Energy Ad Hoc Diesel Fuels committee[2].

Optimization was necessary to obtain a detailed comparison of alternative fuels. Because the fuels under consideration have differing physical and chemical properties, a portion of any change in exhaust emissions measured in Phase I may be due to the response of the engine injection system to differences in the fuel physical properties. The optimization phase of this work involved recalibration of the engine operating parameters that influence engine emissions and fuel economy. These operating parameters include boost level, exhaust gas recirculation (EGR), fuel-injection timing, and pressure in the common rail injection system.

This program is part of an overall study that examines the effect of one oxygenated compound (dimethoxymethane) in diesel fuel on the emissions of particulate matter, oxides of nitrogen, and fuel economy. This program will focus on the chemical characterization of emissions of compounds with known or suspected toxicological properties. A body of work exists[3-10] that suggests fuel property variations can influence the emissions of toxic compounds from diesel engine combustion. In a follow-on phase, the emissions of these compounds using an after-treatment device will be compared to the engine-out emissions to better understand the effects of after-treatment devices. Future research will examine other oxygenated compounds as possible alternatives to dimethoxymethane.

2.0 OBJECTIVE

The overall objective of this project is to better understand the role of fuels on the exhaust emissions of a subset of potentially toxicologically relevant compounds. The three objectives of

this program are to measure the following pollutants collected from diesel engines under a matrix of engine and fuel conditions:

1. polycyclic aromatic hydrocarbon (PAH) content of organic solvent extracts of particulate matter
2. gas phase polycyclic aromatic hydrocarbons
3. other gaseous compounds such as formaldehyde, acetaldehyde, benzene and 1,3-butadiene

These measurements were made on engine out emissions. In future tests other potentially hazardous compounds may have to be measured depending on the technology used in after-treatment devices. For example, if urea were used as a reductant to lower NO_x levels, then compounds relevant to the use of this chemical would need to be measured including, but not limited to urea, ammonia, biuret, and cyanic acid.

3.0 TECHNICAL APPROACH

3.1 Test Engine

The engine used in this investigation was a DaimlerChrysler OM611. The OM611 engine is a 2.2L, direct-injection, compression-ignition, with a Bosch, high-pressure, common-rail, fuel-injection system. The OM611 engine is turbocharged with wastegate control and utilizes an intercooler. The engine design closely matches the specifications of the partnership for a new generation vehicle (PNGV) target compression-ignition direct-injection (CIDI) engine. Characteristics of the OM611 engine are presented in Table 1.

Table 1. OM611 Engine Performance Characteristics

Displacement	2151 cm^3
Maximum Power	92 kW at 4200 RPM
Maximum Torque	300 N-m at 1800 - 2600 RPM
Maximum BMEP	17.5 bar
Compression Ratio	19:1
Minimum Specific Fuel Consumption	203 g/kW-hr

Besides the electronically controlled common rail fuel injection system, the OM611 engine has several other unique features that affect combustion. The engine has two intake ports, one helical for swirl, and one high flow port. The high flow port also contains an Intake Runner Valve (IRV), which is used to shut the port off at low speeds and light loads. This allows for variable swirl in the engine for improving light load exhaust emissions.

The OM611 engine also utilizes variable Exhaust Gas Recirculation (EGR). The EGR is controlled with pulse width modulation of an EGR valve and intake damper, and is referenced to the engine mass air-flow sensor. The high EGR region is from idle to approximately 50% speed and 50 % load. The hot EGR passes through a cooling passage integral with the cylinder head, then on to the intake manifold via he EGR valve.

A feature of the OM611 engine used for controlling both exhaust and noise emissions is the employment of pilot fuel injection. The pilot fuel injection results in a slower start of combustion, which reduces noise levels and may reduce Oxides of Nitrogen emissions. Pilot fuel injection is disabled when the engine is operating above 3000 RPM and 50 % load.

3.2 Engine Setup

3.2.1 Test Cell

The OM611 engine was installed in test cell supplied with conditioned air and attached to an eddy current absorption dynamometer. The engine load was monitored with an electronic load cell. The engine speed was monitored using a 60-tooth gear and a frequency to voltage converter. The fuel system included a constant level day tank, and a Micro-Motion mass flow sensor. Intake air mass flow was measured according to SAE J244 using a Merriam Laminar Flow Element.

The engine was fitted with a gaseous exhaust sample probe and a heated sample line to the emission bench. An exhaust particulate sampling probe was inserted into the exhaust and connected to a 203-mm diameter dilution tunnel. Exhaust dilution ratio was monitored using carbon dioxide tracer. Dilution tunnel sample zone temperature was maintained below 125°F by splitting the engine exhaust.

3.2.2 Electronic Engine Control

The stock engine control unit (ECU) was replaced with the SwRI developed Rapid Prototyping Electronic Control System (RPECS). The RPECS system is a PC-based tool (both hardware and software) that is used for real-time embedded powertrain control system development. The procedure for installing the RPECS hardware involved intercepting and mapping the signals from the stock engine controller. The engine calibration tables and control signals are then duplicated with the RPECS hardware/software in order to control the engine. The operating parameters of interest will be adjusted through changes to the calibration tables in RPECS.

The RPECS has been configured to allow control of the common rail fuel injection system, and intake manifold conditions. The items controllable by RPECS as presently configured are shown in Table 2.

Table 2. RPECS Controlled Engine Parameters

Common Rail Fuel Injection				
Fuel Injection	**Cylinder 1**	**Cylinder 2**	**Cylinder 3**	**Cylinder 4**
Timing	Individual	Individual	Individual	Individual
Duration	Individual	Individual	Individual	Individual
ON/OFF	Individual	Individual	Individual	Individual
Pilot ON/OFF	Global			
Pilot-to-Main Timing	Global			
Pilot Duration	Individual	Individual	Individual	Individual
Pilot/Main Duration Ratio	Individual	Individual	Individual	Individual
Rail Pressure	Global			
Intake Manifold				
Boost - PWM Variable				
Intake Runner Valve - ON/OFF				
EGR - PWM Variable, Intake Mass Air Flow feedback, measured by intake/exhaust CO_2				

The RPECS uses pulse width modulation (PWM) for closed-loop control of EGR, manifold pressure, and the common rail fuel injection pressure. The feedback for the EGR control loop is the engine mass air flow sensor. The manifold pressure sensor provides feedback for RPECS, with the turbocharger wastegate utilized as the control element. The common rail fuel pressure is controlled with a PWM fuel pressure vent, with feedback from a 1500 bar rail pressure sensor.

The RPECS has an eight-channel timer board that synchronizes with the engine crankshaft and camshaft pulses for activation of the fuel injectors. Each cylinder of the engine utilizes two timer

channels, one for the pilot fuel injection event and one for the main fuel injection event. The fuel injectors are powered by peak-and-hold drivers, which allow variation of timing and duration of both pilot and main fuel injection. Additional fuel injection control features include individual cylinder control of pilot and main fuel injection events and pilot/main fuel injection ratio control.

One-dimensional tables, one for speed and one for load, were programmed into RPECS so engine operating conditions could be consistently repeated. The RPECS has the ability to operate in either closed-loop torque or closed-loop speed control. In closed-loop torque control RPECS adjusts fuel injection quantity to attain the set point torque value from the dynamometer electronic load cell feedback. In closed-loop torque mode the engine speed is controlled by an eddy-current dynamometer controller. Closed-loop torque control was used for four of the five operating conditions in this program.

In closed-loop speed control mode, RPECS calculated fuel quantity to maintain a steady engine speed using the crankshaft signal. In this program closed-loop speed control was used at the idle condition. At idle the torque was maintained by controlling dynamometer windage with the dynamometer cooling water flow.

3.2.3 Cylinder Pressure Transducers

Program modifications were made to the RPECS to allow individual cylinder fuel injection timing and quantity control. Pressure transducer adapters were machined to fit in the cylinder head via the glow-plug passages. Kistler 6052A transducers were mounted in the adapters. All cylinder pressure transducers were calibrated, and connected to a DSP Technologies high-speed data acquisition system for combustion analysis and cylinder balance. The DSP was clocked with a 720-pulse/revolution shaft encoder.

3.3 Exhaust Emissions Measurement

The OM611 engine was instrumented for the exhaust species shown in Table 3 and as diagramed in Figure 1. The gaseous emissions were drawn from the raw exhaust, with a sample probe located approximately three pipe diameters downstream of the turbocharger outlet. The gaseous exhaust sampling probe was located upstream of the back pressure regulating butterfly. The backpressure regulating butterfly was locked in the position that produced 11-in-Hg backpressure at rated speed and load. The gaseous emissions sampling was performed in accordance with the

guidelines outlined in 40 CFR Part 86, Subpart D. The OM611 engine exhaust was coupled to the house exhaust system and a Constant Volume Sampling (CVS) system. The CVS system consists of a 203-mm dilution tunnel, with a Variable speed Roots type blower. In order to attain a 125°F filter face temperature with the CVS system, the engine exhaust was split between the house exhaust and the dilution tunnel. The dilution tunnel sample zone temperatures were verified at each of the test modes. The blower speed setting was adjusted to maintain 120°F in the sample zone at Mode 5, the highest speed and load condition.

Table 3. Analytical Instrumentation	
Constituent	**Analysis Method**
Total Hydrocarbon	Heated Flame Ionization Detector
Carbon Monoxide	Non-Dispersive Infrared Analysis
Carbon Dioxide	Non-Dispersive Infrared Analysis
Oxides of Nitrogen	Chemiluminescent Analysis
Particulate Matter	Gravimetric, CVS, CO_2 tracer
Soluble Organic Fraction of PM	Gravimetric, Soxhlet Extraction Toluene/Ethanol
Benzene	Gas Chromatography
1,3-Butadiene	Gas Chromatography
Formaldehyde	DNPH Adsorbent/High Pressure Liquid Chromatography
Acetaldehyde	DNPH Adsorbent/High Pressure Liquid Chromatography
Polycyclic Aromatic Hydrocarbons	Gas Chromatography/Mass Spectroscopy/Selected Ion Monitoring

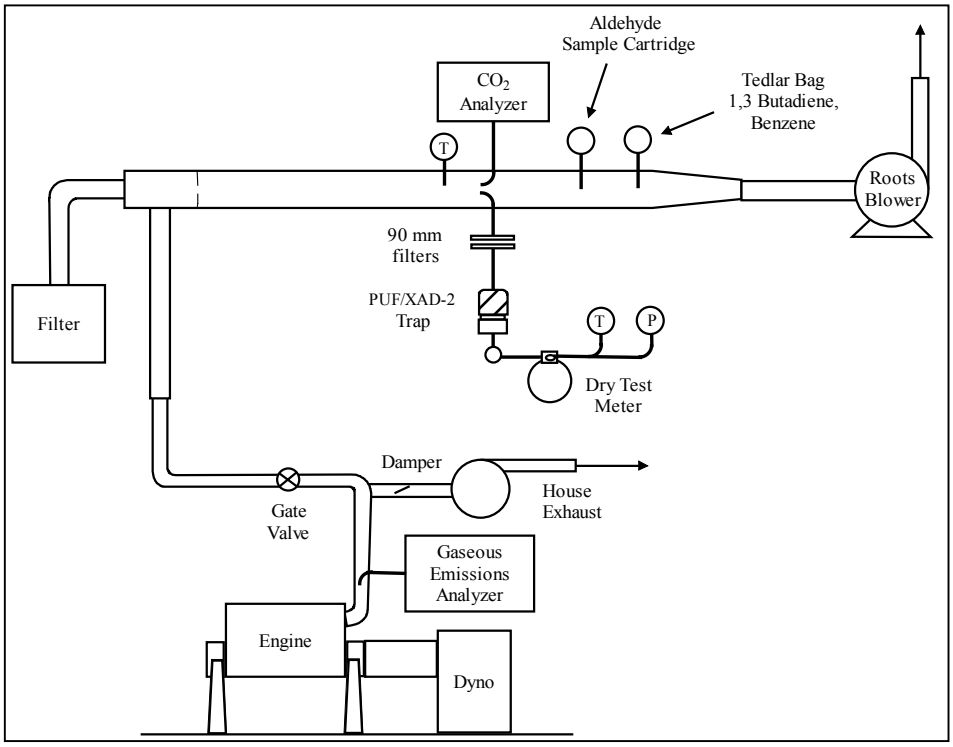


Figure 1. Dilution Tunnel for Particulate and Air Toxin Sampling

A carbon dioxide tracer technique was utilized to determine the dilution ratio in the CVS system. The particulate matter sampling procedures were performed in accordance with the guidelines established in 40 CFR Part 86, Subpart N. A polyurethane foam and XAD-2 resin trap were utilized for sampling gas phase PAH compounds. Soluble phase PAH compounds were extracted from 90 mm filters. Benzene and 1,3-butadiene were collected in a sample bag from the dilution tunnel sample zone. Formaldehyde and acetaldehyde were trapped on a DNPH adsorbent cartridge from the dilution tunnel sample zone.

3.3.1 Gaseous Emissions Analyses

The following three groups of gaseous engine out exhaust emissions were determined for each test point, i.e. engine mode and fuel combination.

3.3.1.1 Typical Exhaust Gases

The following species concentrations were measured utilizing the instrumentation shown in Table3:

- hydrocarbons (HC)
- carbon monoxide (CO)
- carbon dioxide (CO_2)
- oxides of nitrogen (NO_x)
- oxygen (O_2)

3.3.1.2 Toxic Air Pollutants Cited in the Clean Air Act

A sample cart, as seen in Figures 2 and 3, was configured and placed in the test cell near the engine and exhaust dilution tunnel. This cart was arranged so that one technician could effectively collect bag samples and cartridge samples simultaneously. The cart was utilized for sampling the following four Clean Air Act toxic air pollutants:

- benzene
- 1,3-butadiene
- formaldehyde
- acetaldehyde

The front of the cart was used to control and monitor the cartridge sampling for formaldehyde and acetaldehyde while the back of the cart supported the pumps and metering valves for collecting the bag samples for benzene and 1,3-butadiene analyses.

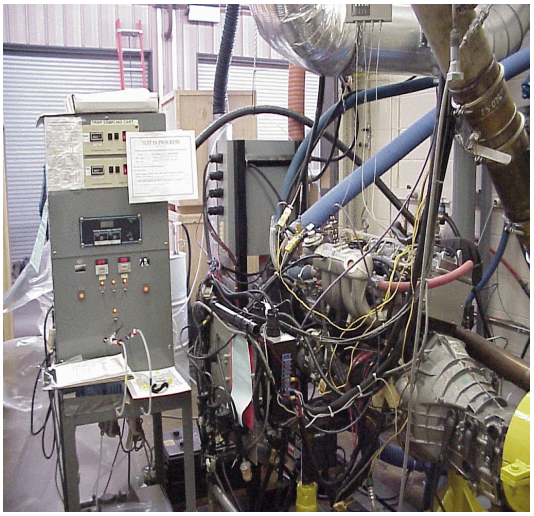


Figure 2. Gas Sampling Cart – Front

Figure 3. Gas Sampling Cart Rear

3.3.1.2.1 Benzene and 1,3-Butadiene

Exhaust samples for benzene and 1,3-butadiene determination were taken in Tedlar7 bags via a diaphragm vacuum pump from a dilution tunnel through an unheated 1/4" Teflon tube. A corresponding background air sample was taken from the ambient air. The collected samples were transported to the SwRI Department of Emissions Research (DER) for analysis. These two toxic air pollutant compounds were analyzed using two different gas chromatographs (GC) as described in Table 4. The two GCs were configured and operated according to the CRC Auto-Oil Phase II Air Quality Improvement Research Program guidelines.[(1)] These instruments were calibrated with CRC/NIST gas mixtures according to DER Standard Operating Procedures. Detection limits for the GCs are on the order of 10 parts per billion.

Table 4. Gas Chromatographic Analysis Parameters

	1,3-Butadiene	**Benzene**
Gas Chromatograph	Hewlett- Packard 5890-II	Hewlett- Packard 6890
Injector	10 port gas sampling valve w/ 5 mL sample loop	10 port gas sampling valve w/ 5 ml sample loop
Detector	hydrogen flame ionization	hydrogen flame ionization
Column/s	DB-Wax, 15 meter x 0.53mm, 1.0 film, J&W Scientific, Alumina PLOT/KCL, 50meter x 0.53mm, 10 µm film, Chrompack, International	pre-column: 2 meter of 0.25 mm I.D. deactivated fused silica Analytical column:30 m x 0.25 mm DB-5, 0.25 □m film thickness

3.3.1.2.2 Formaldehyde and Acetaldehyde

To collect the aldehydes, a metered volume of the dilute exhaust was transferred with a diaphragm vacuum pump from the dilution tunnel through a heated sample transfer line and heated particulate filter, both maintained at 375°F and finally through a cartridge containing silica impregnated with 2,4-dinitrophenylhydrazine (DNPH), Figure 4. A metered volume of the background air was pulled through another cartridge. A Hastings model HFC-202D mass flow meter was used to measure the volume of gases sampled. Air temperature and barometric pressure were recorded by the engine control computer. Any aldehyde or ketone present in the sampled gas reacted quickly with the DNPH to form a stable derivative (R-CHO phenylhydrozone). These derivatives were extracted from the trap with ultra-pure acetonitrile. Analysis of the extracted samples and backgrounds were performed using a high performance liquid chromatograph (HPLC), pumping a ternary solvent gradient of water, methanol, and acetonitrile through an ultra-violet (UV) spectroscopic detector. The instrument was calibrated using purified aldehyde derivatives according to the DER Standard Operating Procedures. The detection limit for this instrument is on the order of 0.005-ppm aldehyde in dilute exhaust.

Figure 4. Sample Cartridges

The collection of optimum sample volumes during the engine test modes required precise timing of starting and stopping pumps and opening and closing valves by the cart operator. Appendix A describes the sequence of these events. Revision to the first sequence was determined necessary when HPLC analyses indicated overloading or breakthrough of the DNPH aldehyde cartridges. Background cartridge samples were a composite of one entire day of sampling.

3.3.1.3 Gaseous PAH compounds

The gaseous phase (PUF/XAD-2 trap) samples are Soxhlet extracted with methylene chloride for 18 hours. At the beginning of the extraction, a PAH surrogate spiking solution containing three deuterated PAH [benzo(b)fluoranthene-d12, benzo(a)anthracene-d12, and dibenz(a,h)anthracene-d14 at 100 nanograms each] is spiked into the sample. Sample extracts are then concentrated and solvent exchanged into hexane. A cleanup procedure that consists of an acid wash and liquid chromatography is then applied. The acid used is a diluted sulfuric acid. The chromatography is performed on a silica gel column that would separate fuel and oil from the PAHs. The sample extracts were in hexane, transferred onto the Si column, the column flushed with hexane (to remove the fuel and oil), and the PAHs were then eluted out of the column by using a DCM/pentane solvent system. The sample extracts, after the cleanup, were blown down to a final volume of 100 microliters (uL). An internal standard mixture containing deuterated PAH is added to these extracts prior to GC/MS/SIM (selected ion monitoring) analysis. Two or three characteristic ions of each PAH are monitored. A PAH calibration curve consisted of at least 5 points is obtained prior to the sample analysis. A solvent or lab blank is analyzed immediately after the last calibration standard analysis to ensure no significant carryover occurs on the instrument. The PAH are analyzed in the positive ion electron impact (PI/EI) mode. Separate GC/MS/SIM analyses are necessary to acquire the PAH data.

The estimated detection limits (DLs) are 1.0 nanogram (total) per PAH per sample. This is based on the lowest calibration standard of 0.01 ng/uL/PAH with a 100 uL final volume. Note, different target compounds behave differently on the instrument and, therefore, exert different final DLs. The DLs given here should be considered as estimated values. There are other factors such as massive interference, and/or split samples for other analyses that will inevitably increase the DLs. A PUF/XAD-2 filter blank was extracted with each set of engine PUF/XAD-2 filters. The PUF/XAD-2 blank was analyzed to determine the PAH background from the media. Additionally three PUF/XAD-2 tunnel blanks were analyzed to determine the PAH background from the test cell, dilution tunnel, and sample system. The tunnel blanks were drawn for one

hour; the background values that are reported in Table 5 have been adjusted to represent the 30-minute sample time that was used during engine testing. Included in Table 5 is the reported detection limits for each gaseous phase PAH compound. The gaseous phase PAH compounds were analyzed using a high-resolution gas chromatograph with a 1.0 atomic mass unit (AMU) low-resolution mass spectrographic detector. There was not any non-detects for gaseous phase PAH compounds during testing.

Table 5. Gaseous Phase PAH Backgrounds and Detection Limits

COMPOUND	Average PUF/XAD-2 Filter Blank	Average PUF/XAD-2 Tunnel Blank	PUF/XAD-2 Extract HRGC/LRMS(1 AMU) Detection Limit
	ng/sample	ng/sample	ng/sample
naphthalene	369	2227	10
2-methylnaphthalene	181	945	10
1-methylnaphthalene	132	572	10
2,6-dimethylnaphthalene	105	618	10
acenaphthylene	102	113	10
acenaphthene	105	114	10
fluorene	113	192	10
phenanthrene	128	597	10
anthracene	112	22	10
fluoranthene	104	22	10
pyrene	101	22	10

3.3.2 Exhaust Particulate Matter Analyses

The soluble organic fraction of diesel exhaust particulate collected on 90 mm Pallflex filters was removed from the particulate using a Soxhlet extraction system. The extraction solvent was 30 percent toluene/ 70 percent ethanol by volume. One hundred microliters of a PAH surrogate spiking solution, containing three deuterated PAH (benzo(b)fluoranthene-d12, benzo(a)anthracene-d12, and dibenzo(a,h)anthracene-d14, at 100 nanograms each) was syringed onto each filter prior to solvent extraction to determine the PAH extraction efficiency. This Soxhlet extraction method is similar to washing the filter with approximately five gallons of solvent. The percent mass extracted from the diesel particulate on the filter is determined by weight loss, usually in milligram quantities, after solvent extraction and drying.

The exhaust particulate were analyzed for Soluble Organic Fractions (SOF) and specific PAH compounds following EPA Protocol 8100. The particulate (filter) samples are analyzed the same way as described above for the PUF/XAD-2 samples except the solvent used for the PM filter extraction is ethanol/toluene (30/70; v/v).

Three 90-mm Pallflex filter blanks were extracted and analyzed to determine the PAH background from the media. Additionally, three 90-mm Pallflex tunnel blanks were analyzed to determine the PAH background from the test cell, dilution tunnel, and sample system. The tunnel blanks were drawn for one hour; the background values that are reported in Table 6 have been adjusted to reflect the 30-minute sample time that was used during engine testing. Included in Table 6 is the reported detection limits for each gaseous phase PAH compound for two analytical instruments. Due to low levels of contamination, the filter and tunnel blanks had lower detection limits than the SOF extracts. The particulate matter PAH compounds were initially analyzed using a high-resolution gas chromatograph with a 1.0 atomic mass unit (AMU) low-resolution mass spectrographic detector. Depending on the engine-operating mode and test fuel utilized, there were non-detect values for several key PAH compounds. Primarily, the non-detects were reported due to interference from other organic compounds around the molecular weight of the compound of interest. For the higher molecular weight PAH compound shown in Table 6, a high-resolution gas chromatograph with a 0.01 atomic mass unit (AMU) high-resolution mass spectrographic detector was used for selected test runs.

Table 6. Particulate Matter PAH Backgrounds and Detection Limits

COMPOUND	Average Pallflex 90mm Filter Blank		Average Pallflex 90mm Tunnel Blank		SOF Extract HRGC/LRMS(1AMU) Average Detection Limit	SOF Extract HRGC/HRMS(0.01AMU) Average Detection Limit
	ng/sample	DL	ng/sample	DL	ng/sample	ng/sample
Naphthalene	543	3	245	4	10	
Acenaphthylene	9	3	8	4	10	
Acenaphthene	74	3	37	4	10	
Fluorene	120	3	62	4	10	
Phenanthrene	665	3	370	4	10	
Anthracene	63	3	16	4	10	
Fluoranthene	89	3	85	4	10	
Pyrene	41	3	67	4	10	
Benzo[a]anthracene	1	3	2	4	10	
Chrysene	3	3	5	4	10	
Benzo[b]fluoranthene	1	3	6	4	10	
Benzo[k]fluoranthene	1	3	4	4	10	
Benzo[e]pyrene	1	3	3	4	10	
Benzo[a]pyrene	0.6	3	1	4	10	0.1
Indeno(1,2,3-cd)pyrene	ND	3	2	4	10	0.1
Dibenzo[a,h]anthracene	ND	3	1	4	10	0.25
Benzo[ghi]perylene	0.9	3	3	4	10	0.1

3.4 Measured Quantities and Accuracy

Table 7 shows the estimated accuracy of the engine and emission measurements.

Table 7. Measured Quantities			
Quantity	**Description**	**Unit**	**Accuracy**
Engine Speed		rpm	+/- 4.2
Engine Load		ft-lb	+/- 2.3
Fuel Flow		lb/hr	+/- 5 %
Temp. Coolant In		°F	+/- 4
Temp. Coolant Out		°F	+/- 4
Temp. Oil		°F	+/- 4
Temp. Intake Air		°F	+/- 4
Temp. Fuel		°F	+/- 4
Temp. Exhaust		°F	+/- 25
Temp. Intercooler In		°F	+/- 4
Temp. Intercooler Out		°F	+/- 4
Temp. Air Dewpoint		°F	+/- 4
Pres. Ambient		"Hg	+/- 1%
Pres. Exh. Restriction		"Hg	+/- 1%
Pres. Boost Pre-Intercooler		"Hg	+/- 1%
Pres. Boost Post-Intercooler		"Hg	+/- 1%
Carbon Monoxide	CO	g/kW-hr	+/- 15 %
Hydrocarbon	HC	g/kW-hr	+/- 20 %
Nitric Oxides	NO_x	g/kW-hr	+/- 10 %
Carbon Dioxide	CO_2	g/kW-hr	+/- 10 %
Particulate (Total)	PM	g/kW-hr	+/- 20 %

3.5 Fuels

Five fuels were evaluated in this program and are described in Table 8.

Table 8. Fuels Descriptions		
Test Fuel	**Fuel Code**	**Fuel Description**
1	CA	California Reference Diesel
2	ADMM15	Blend: 15% Dimethoxymethane (DMM) with 85% ALS Diesel
3	FT-100	Neat Fischer-Tropsch Diesel
4	ALS	Low Sulfur Diesel, Low Aromatics
5	DF-2	EPA Certification Grade Diesel

Fuel analyses are provided in Appendix B from previous work. Fuel properties of interest are shown in Table 9.

Table 9. Fuel Property Summary						
Fuel (Code)	H,wt%	C,wt%	O,wt%	Cetane Number	Sulfur, ppm	Aromatics, wt%
California Reference Diesel Fuel (CA)	13.4	86.4	0.2	45	176	18.9
Low Sulfur Diesel Fuel (ALS)	14.4	85.6	0.0	63	1	9.0
Fischer-Tropsch Diesel (FT-100)	15.1	84.8	0.1	84	1	0.2
Oxygenate Blend: 15% Dimethoxymethane in ALS (ADMM15)	13.7	81.6	4.7	59	1	8.2
EPA 2D Certification Fuel (DF-2)	13.0	86.7	0.3	44	337	30.3

3.6 Engine Lubricant

A synthetic lubricant, SAE 5W30 viscosity grade, was used in this project. A synthetic oil will have less volatile fractions than a petroleum-based lubricant, which will minimize oil contribution to exhaust particulates. Frequent oil changes were made to minimize the engine oil contaminant contribution to exhaust particulates.

4.0 DESIGN OF EXPERIMENT

4.1 Steady-State Operating Conditions

The engine was installed in a steady-state test cell. The engine was supplied with conditioned intake air, controlled to EPA intake conditions. EPA intake air conditions are shown in Table 10.

Table 10. EPA Intake Air Conditions		
Parameter	Set Point	Tolerance
Intake Pressure	100 kPa	±1 kPa
Intake Temperature	25 °C	±2 °C
Intake Dew Point	15 °C	±1 °C

4.1.1 Modes

Five modes of steady-state operation (speed/load points) were included in these investigations. Table 11 shows the engine steady-state test points while Figure 5 shows these five points in relation to the baseline torque curve.

Table 11. Steady-State Test Points			
Mode	BMEP, bar	RPM	MB Equiv. Torque, ft-lb_f
M12	0.10	900	1-2
M11	2.62	1500	33.1
M10	2.00	2000	25.3
M6	4.20	2300	53.0
M5	8.80	2600	111

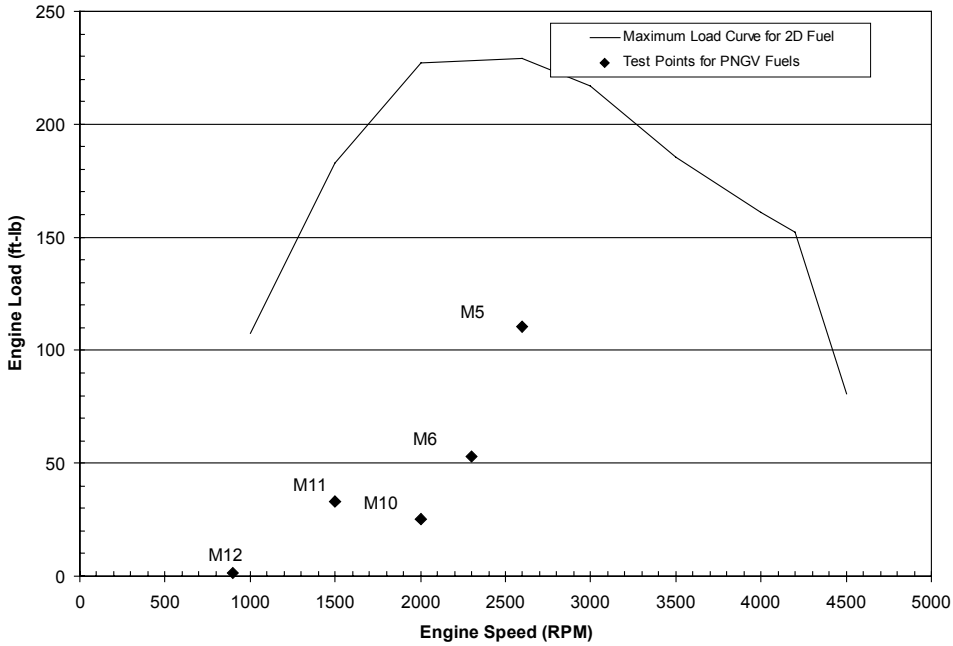


Figure 5. Speed/Load Points for Auto/Energy Fuels

4.1.2 Location of Peak Pressure (LPP)

The OM611 engine utilizes pilot injection. The pilot injection was turned off for the LPP phase of the toxicology study. The OM611 engine was operated at each of the test modes with EGR levels as prescribed by the Auto/Energy CIDI Ad Hoc fuels committee. The Location of Peak Pressure (LPP) was held as constant as feasible for each test mode and test fuel. The IMEP in each cylinder was matched within 5%. The engine was operated with the DaimlerChrysler calibrations for fuel injection rail pressure, boost, and intake runner valve position.

The LPP was established for the OM611 engine by determining MBT timing at a fixed rail pressure and fixed injection duration utilizing CARB fuel for each test mode. The procedure for each test mode was as follows:

1. Check motoring trace on each cylinder, find encoder offset.
2. Turn OFF pilot injection.
3. Establish proper IRV position.
4. Set fuel injection rail pressure.
5. Set EGR level.

6. Fix injection duration that meets BMEP target.
7. Determine IMEP for cylinder balance; adjust individual cylinder injection duration.
8. Establish MBT, starting at 7°ATDC LPP, advance and retard timing.
9. Determine LPP at MBT, and determine base injection duration offsets for IMEP balance.
10. Update Controller tables for fuel injection timing and duration.

4.1.3 Cylinder Balance

The DaimlerChrysler OM611 engine will have a Kistler 6052A piezoelectric pressure transducer installed in each of the four cylinders via a glow plug adapter. The cylinder pressures were monitored with a DSP high-speed data acquisition system clocked at 0.5° crankshaft intervals. The DSP data system will be set up to monitor Location of Peak Pressure (LPP) and Indicated Mean Effective Pressure (IMEP) for each cylinder. The DSP was also used to calculate engine average IMEP and LPP for 50 consecutive combustion cycles. During testing, the RPECS control system was able to maintain IMEP within 5% cylinder-to-cylinder, and hold LPP within 2 crankangle degrees cylinder-to-cylinder for all modes.

During testing, the OM611 engine was operated at the conditions that follow in Table 12 with the pilot fuel injection turned off:

Table 12. Engine Operating Conditions

Mode	RPM	BMEP, bar	EGR, %	Rail Pressure, bar	Boost, bar g	LPP Timing, °ATDC	IMEP, cyl. To cyl. %	IRV Status
12	900	0.2	40	Stock	Stock	7	±5	Closed
11	1500	2.62	30	Stock	Stock	7	±5	Closed
10	2000	2.0	30	Stock	Stock	7	±5	Closed
6	2300	4.2	15	Stock	Stock	7	±5	Open
5	2600	8.8	5	Stock	Stock	7	±5	Open

The cylinder balance procedure was as follows:

1. Set Test Mode, RPECS will do closed loop torque control by dithering injection duration.
2. Set EGR level.
3. Make individual cylinder timing changes to meet LPP for MBT.
4. Average IMEP for all four cylinders.
5. Adjust individual injection duration offsets to set cylinder IMEP within ±5% of the average IMEP.

6. Iterate between timing changes and IMEP adjustments.
7. Update Controller tables for timing and duration offsets.
8. Stabilize engine at balanced IMEP and LPP.
9. Initiate particulate and gaseous emission sampling.
10. Spot Check IMEP and LPP during particulate sampling.

4.1.4 Pilot Fuel Injection

A brief pilot fuel injection evaluation was performed to determine if differences in exhaust emissions existed between modes operated with and without pilot fuel injection. The approach was to operate the engine at each of five test modes, utilizing three differing control strategies, and using CARB fuel. The control approaches consisted of locating peak pressure (LPP) without pilot injection, LPP with pilot injection (Pilot A), and the calibrated (Pilot B) engine strategy, which also uses pilot injection. The LPP and Pilot A strategies were performed using an RPECS controller. Under RPECS control, each cylinder was balanced within 5% of the engine average IMEP. The Pilot B strategy was performed with the OEM controller. The LPP was determined by fixing injection rail pressure, specified EGR, and setting the injector pulse width that meets the BMEP setting for the mode. The main start of injection timing was swept, and the LPP that produced the best torque was noted. When the location of peak pressure during Pilot A operation was determined, the pilot-to-main, injection-pulse-width ratio and the pilot-to-main timing gap remained as the calibrated settings for the mode.

The basic findings during the brief evaluation concerned the PM and Soluble Organic Fraction of the PM. The PM emissions increased when pilot injection was utilized. However, pilot injection results in a higher exhaust temperature that reduces the SOF level of the particulate.

The conclusions from the study were that the pilot fuel injection operation does affect emissions, noise, and BSFC. The heat release traces show early combustion, which could lead to variations in exhaust compounds. For the non-idle modes, pilot injection reduces noise and NOx, increases PM and BSFC, and reduces the SOF of the PM. Combustion heat release analysis reveals reactions that occur BTDC, with long in-cylinder residence time of the pilot injected fuel. Differences in combustion and emissions warrant investigation of pilot injection. For the idle mode, the results were variable. The higher EGR at idle, using the Pilot B (OEM) strategy, probably had more effect on emissions than the actual pilot injection event. Detailed results from the pilot fuel injection study are available in Appendix C.

The following recommendations were presented to DOE and the Auto/Energy CIDI Ad Hoc fuels committee following the brief pilot fuel injection evaluation:

- Complete tests as planned without pilot injection for all five fuels.
- Perform tests with pilot injection using LPP with addition of pilot fuel injection and using the OEM ECM strategies.
- Use OEM calibrated pilot-to-main gap of 1.8 ms.
- Use OEM calibrated pilot-to-main, pulse-width ratio for BMEP, for each fuel.
- Evaluate all five fuels using pilot fuel injection.
- Evaluate at two modes weighted highly by Ad Hoc fuels study:
  - mode 11: 1500 rpm/ 2.62 bar BMEP
  - mode 10: 2000 rpm/ 2.0 bar BMEP
- Perform experiments in triplicate.

4.1.5 Intake Runner Valve

The engine has an Intake Runner Valve (IRV) for increasing swirl at low-speeds, light-loads. The IRV works by closing off one of the two intake ports, forcing the entire intake charge down the other intake tract. The status of the IRV under Bosch ECM control is as shown in Table 13 for the five test modes.

Table 13. Modal Intake Runner Valve Positions

Mode	RPM	BMEP, bar	IRV Status
12	900	0.2	Closed
11	1500	2.62	Closed
10	2000	2.0	Closed
6	2300	4.2	Open
5	2600	8.8	Open

For the toxicology study, the IRV was utilized as calibrated by DaimlerChrysler. Changing the in-cylinder charge air motion by varying IRV status could alter combustion and impact the results for the OM611 engine.

4.2 Test Plan

4.2.1 LPP Tests

Best torque injection timing sweeps were performed at all modes to determine the LPP at the specified EGR. The engine was controlled with pilot injection off, specified EGR, and at the fixed injection pulse width to maintain the brake mean effective pressure operating target. The IMEP was monitored on each cylinder, along with LPP, to be maintained within the criteria discussed previously. Injection timing was swept until a change in brake torque was noted. For all modes, a LPP of 7°ATDC corresponded with the best torque timing.

The cylinder pressures were monitored and Location of Peak Pressure (LPP) and Indicated Mean Effective Pressure (IMEP) control were verified for each cylinder. The RPECS system was able to maintain IMEP within 5% cylinder-to-cylinder, and hold LPP within 2 crank angle degrees cylinder-to-cylinder for all modes.

All control parameters for the RPECS were verified for maintaining cylinder balance, constant LPP, and specified EGR. A tunnel blank was performed to evaluate sample system toxic air pollutants and PAH concentrations.

4.2.2 Pilot Fuel Injection Tests

To determine if pilot fuel injection on a direct-injected diesel engine with a Common-Rail fuel system exhibits impacts on engine gaseous, PM, toxic air pollutant, and PAH exhaust emissions, evaluations were performed at two modes (10 and11) with three control strategies.

The control approaches consisted of Location of Peak Pressure (LPP) without pilot injection, LPP with Pilot Injection (Pilot A), and the calibrated OEM (Pilot B) engine strategy which also uses pilot injection. When Pilot A control was utilized, the pilot-to-main injection pulse width ratio, and the Pilot-to-Main timing gap was kept the same as the Pilot B settings for the mode.

The timings for the differing control strategies are outlined in Table 14 for each of the test modes. Note the LPP for the Pilot B strategy shown is for the CA fuel, the other test fuels would likely result in a different LPP using the OEM controller. With the OEM controller there was not any timing adjustments available to control LPP with each test fuel. Also note the higher EGR with the Pilot B strategy.

Table 14. Timing Parameters for Pilot Fuel Injection Study –CA Fuel							
Mode	Speed	BMEP, bar		Pilot A			
				LPP	PSOI†	MSOI	EGR, %
11	1500	2.62		7	24	8	30
10	2000	2		7	31	10	30
LPP				Pilot B			
LPP*	MSOI‡	EGR, %		LPP	PSOI	MSOI	EGR, %
7	9	30		12	18	2	36
7	12	30		15	23	2	35
*LPP - Location of Peak Pressure, dATDC ‡MSOI - Main Start of Injection, dBTDC †PSOI – Pilot Start of Injection, dBTDC							

4.3 Statistical Analysis Methodology

The goal of this study was to provide information on the PAH content of exhaust gas and exhaust particulates, some of which have been shown to cause tumors in animals. In addition to investigating PAH content, toxic air pollutants and mass emissions were also studied. The engine test results were used to compare the PAH levels of four modified diesel fuels and a baseline fuel to determine the effect of fuel modifications on the total emissions of these toxicologically important compounds. Additionally, the mode (speed and load) of engine operation and the pilot condition settings were also controlled to assess their effects on the PAH or emissions response.

Analysis of variance (ANOVA) statistical techniques[11] were used to investigate the factor effects of fuel, mode, and pilot condition using models on four different data segments. These four data segments included engine test results from the following scenarios:

(1) LPP only condition for modes 5, 6, 10, and 11;

(2) LPP only condition for mode 12;

(3) LPP and pilot on conditions for modes 10 and 11; and

(4) LPP only condition for weighted modes 5, 6, 10, and 11.

Each of these four data segments included independent ANOVA models on the 38 measured responses which included: five typical gaseous emissions, four toxic air pollutant emissions, 11 gaseous PAH emissions, 17 specific PAH from SOF, and one SOF. Each fuel, mode, and pilot condition combination was run in triplicate. The ANOVA identified which factors were statistically significant with respect to the average response. For example, the ANOVA tested whether the average response of the five fuels was statistically different. It also determined if significant differences existed across the modes, and whether an interaction between the fuel and mode was significant. If significant differences existed, a Tukey's HSD post-hoc multiple comparison procedure[12] was conducted to discriminate between the response averages across the levels of the significant factor. All comparison tests were made at the 5% level of significance.

No mathematical transformations were made on any of the response variables (PAH content, toxic air pollutants and mass emissions). All analyses were conducted in the original response variable units. The units used for the PM and SOF emissions were g/kW-hr, toxic air pollutant emissions were mg/kW-hr, soluble PAH were micro-grams/kW-hr, and the gaseous PAH were micro-grams/kW-hr.

The ANOVA models used for each of the four data segments are described below.

LPP only condition for modes 5, 6, 10, and 11 - Using only the pilot off condition data, an ANOVA was performed using the 5 fuels and 4 modes (5, 6, 10, and 11). This ANOVA model contained a FUEL and MODE effect along with a FUEL by MODE interaction.

LPP only condition for mode 12 - Using only the pilot off condition data, an ANOVA was performed using the 5 fuels and only Mode 12. Thus, there was not a MODE effect in the ANOVA but only a FUEL effect.

LPP and pilot on conditions for modes 10 and 11 - In comparing the responses across the 3 different pilot conditions, only modes 10 and 11 were used. Data from the 5 fuels, 2 modes and 3 pilot conditions were used in an ANOVA model that included the FUEL, MODE, and PILOT effects along with all 2-way interactions and a 3-way interaction.

LPP only condition for weighted modes 5, 6, 10, and 11 - The final analysis included a composite response that was computed by weighting 4 modes (5, 6, 10, and 11) according to the Ad Hoc Diesel Fuels Panel weighting criteria. The composite was computed as:

(25/1200)*response@Mode 5 + (200/1200)*response@Mode 6 +
(375/1200)*response@Mode 10 + (600/1200)*response@Mode 11

A composite response was computed for each test mode set run with each fuel. Since each fuel, mode, and pilot condition combination was run in triplicate, a composite response was determined from the test results for modes 5, 6, 10, and 11 that were run nearest to one another. This usually occurred on the same test day. Therefore, three composite responses were computed for each PAH, toxic air pollutants and mass emissions. However, there were four soluble PAH responses that resulted in non-detects in one or two modes in the ALS, CA or DF-2 fuels. These responses were acenaphthylene, fluorene, benzo[b]fluoranthene, and benzo[e]pyrene. In each of these soluble PAH cases only one composite response could be computed. Therefore, the remaining two composite responses were calculated based on imputed values for the non-detects. The missing PAH values were replaced with either the lowest actual measurement for that mode and fuel or the lower detection limit for that mode and fuel. In situations where two of the three composite responses were computed, no imputed values were used to replace the one missing composite response.

Using only the pilot off condition data and the composite responses, an ANOVA was performed using the 5 fuels. Thus, there was not a MODE effect in the ANOVA - only a FUEL effect.

5.0 FUEL IMPACT ON EMISSIONS – WEIGHTED LPP RESULTS

Fuel comparisons utilizing the Ad Hoc Fuels Group Mode Weighting Factors shown in Table 15 were made for brake specific exhaust emissions with the engine operated under LPP control with pilot fuel injection turned off. Mode 12 was not included in the weighting scheme due to the combination of variability of the mode 12 data and the large mode 12 weight which masked the fuel effects on emissions. The ANOVA tables for the weighted averages can be found in Appendix C.

Table 15. Weighting Factors for Engine Out Emissions	
Mode	**Mode Weights, seconds**
Mode 11	600
Mode 10	375
Mode 6	200
Mode 5	25
Total	1200

5.1 Fuel Impact on Regulated Brake Specific Mass Emissions

Several statistically significant trends, at 95% confidence, were apparent from an ANOVA of the weighted average brake specific emissions data. Table 16 summarizes the general rank order for the regulated weighted average mass emissions during LPP engine operation with pilot fuel injection turned off. The table displays the fuels rank from highest response to lowest response for the Least-Square means of the weighted analysis. Statistically significant similar fuel groupings are also shown for each emission response in Table 16.

The discussions to follow are summaries of the ANOVA performed for each emission response for the weighted averages, and refer to the results in Table 16. The ANOVA tables for the weighted averages can be found in Appendix C.

5.1.1 Fuel Impact on Particulate

ANOVA revealed statistically significant differences in the average weighted particulate among the test fuels. The statistical groupings and relative levels of particulate matter emissions are shown in Figure 6 for the test fuels. Average particulate at fuels FT-100 and ADMM15 are not significantly different from one another, but are different than the other three fuels. The average particulate at Fuel ALS is significantly different than Fuel DF-2. The CA fuel is not significantly different than either the ALS or DF-2 fuel for particulate.

5.1.2 Fuel Impact on NOx

The ANOVA revealed statistically significant differences in the average weighted brake specific NO_X among the fuels. From Figure 7 the highest NOx emitter was DF-2, followed jointly by ADMM15, FT-100, and CA, with ALS being the lowest NOx emitting fuel. The average weighted $BSNO_X$ for the DF-2 fuel is significantly different from the remaining four fuels. Another significant finding is the average weighted $BSNO_X$ for the ADMM15 fuel blend is significantly different than the ALS fuel. ALS was the base fuel for the ADMM15 blend.

Table 16. Weighted Mass Emissions (g/kWh) ANOVA Summary for LPP Only Conditions

	LPP Only – Weighted Modes 5,6,10,11		
Response	**Fuel**	**LS Means[1]**	**Significant Fuel Groups[2]**
BSPM	DF-2	0.2888	A
	CA	0.2627	AB
	ALS	0.2249	B
	ADMM15	0.1431	C
	FT-100	0.1337	C
$BSNO_X$	DF-2	4.331	A
	ADMM15	3.719	B
	FT-100	3.441	BC
	CA	3.431	BC
	ALS	3.145	C
BSHC	DF-2	1.428	A
	CA	1.221	A
	ALS	0.7848	B
	ADMM15	0.6766	B
	FT-100	0.3935	C
BSCO	DF-2	5.063	A
	CA	4.931	A
	ALS	3.236	B
	ADMM15	3.095	B
	FT-100	1.830	C
$BSCO_2$	ADMM15	959.4	A
	DF-2	948.0	AB
	CA	911.9	BC
	ALS	910.9	BC
	FT-100	874.2	C
BSSOF	DF-2	0.2279	A
	CA	0.2207	A
	ALS	0.1608	B
	ADMM15	0.1237	C
	FT-100	0.0723	D

[1]Fuels listed from highest to lowest least squares mean

[2]Letters designate groups of fuel means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

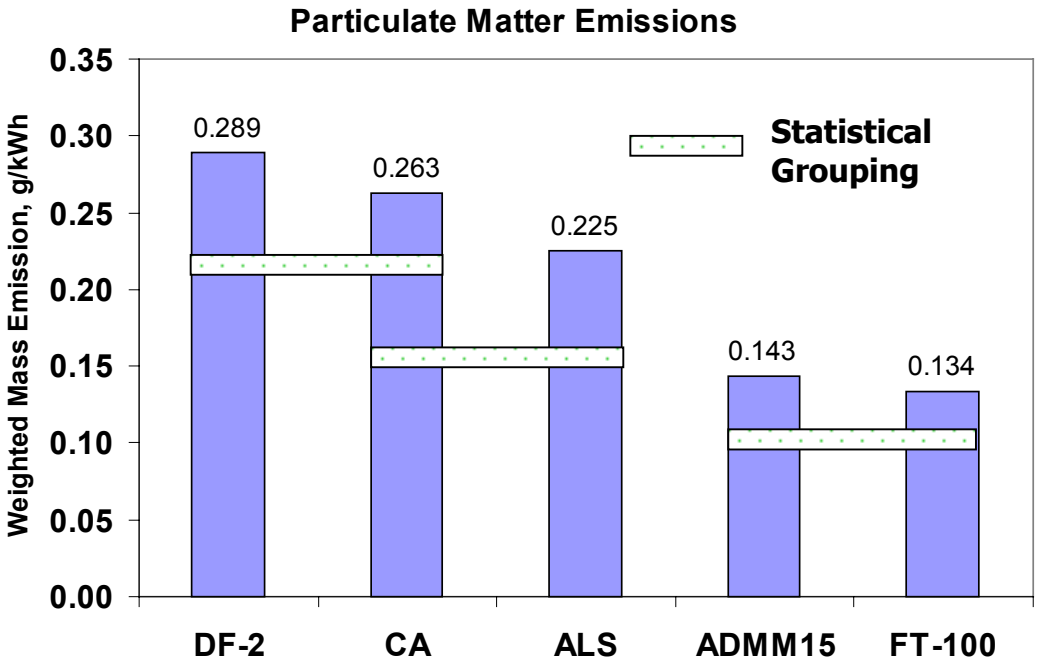


Figure 6. Test Fuel Weighted Average Particulate Matter Mass Emissions (g/kWh)

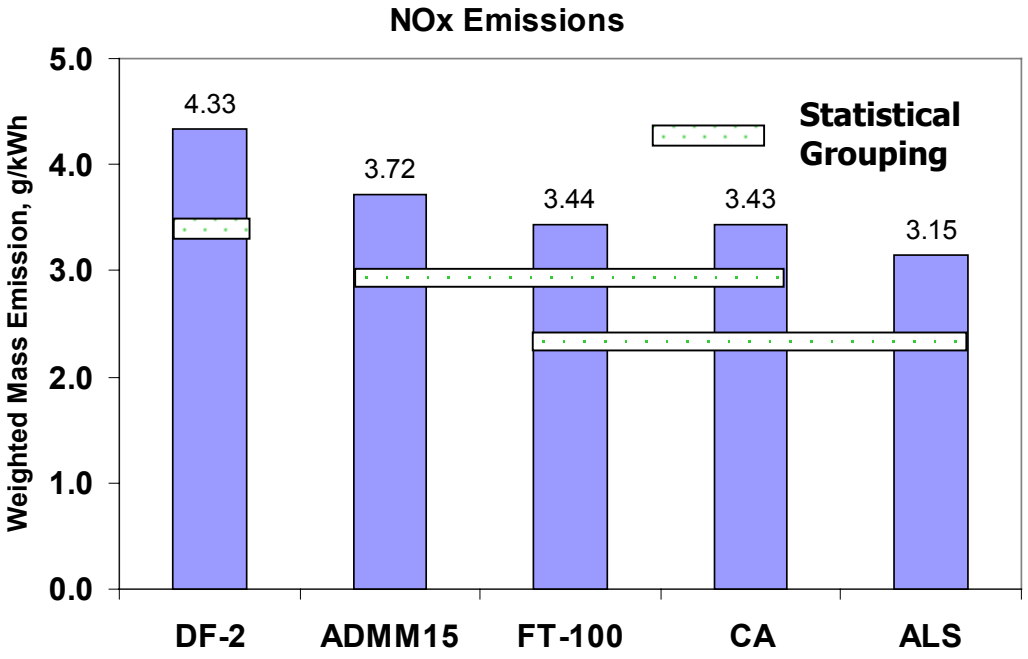


Figure 7. Test Fuel Weighted Average NOx Mass Emissions (g/kWh)

5.1.3 Fuel Impact on HC

A statistically significant difference in the average weighted BSHC among the test fuels was seen from the ANOVA. Figure 8 shows the relative levels of test fuel hydrocarbon emissions, with statistically similar groupings shown with horizontal bars. The average weighted BSHC for the FT-100 fuel is significantly different from the remaining four fuels. The other fuels can be divided into two distinct fuel groupings. The ADMM15 and ALS fuels are not significantly different from one another, but are different from the CA and DF-2 fuels. The CA and DF-2 fuels are not significantly different from one another.

5.1.4 Fuel Impact on CO

Figure 9 shows the ANOVA statistically significant differences in the average weighted BSCO among the fuels. The average weighted BSCO for the FT-100 fuel is significantly different from the remaining four fuels. The other fuels can be divided into two distinct fuel groupings. The ADMM15 and the ALS fuels are not significantly different from one another, but are different from the CA and DF-2 fuels. The CA and DF-2 fuels are not significantly different from one another. The CO and HC results show the same statistical trends, which is not unexpected considering both species are measures of combustion inefficiency.

5.1.5 Fuel Impact on CO_2

The ANOVA results for $BSCO_2$ reveal statistically significant differences in the average weighted response among the fuels. Figure 10 shows the statistical groupings for CO_2. The average weighted $BSCO_2$ for the ADMM15 fuel is significantly different than the ALS, CA, and FT-100 fuels. Also, the average weighted $BSCO_2$ for the FT-100 fuel is significantly different than the DF-2 fuel. CO_2 emissions are a measure of energy consumption, and in the case of the test fuels reflects the fuels heating value. ADMM15 has the lowest net heat of combustion of the test fuels, which results in the highest CO_2 emissions. FT-100 has the highest heating value, and correspondingly lowest CO_2 emissions.

5.1.6 Fuel Impact on SOF of PM

From the ANOVA statistically significant differences in the average weighted BSSOF among the fuels exists. The relative SOF levels of the particulate matter and their statistical groups are

represented in Figure 11. There are four distinct fuel groupings with respect to the average weighted BSSOF. The FT-100, ADMM15, and ALS fuels are significantly different from one another and the remaining two fuels. The CA and DF-2 fuels are not significantly different from one another, but are significantly different from the other three fuels.

The SOF represents the portion of the total particulate that includes unburned fuel, unburned lube oil, and byproducts of combustion of fuel and lube oil. Although ADMM15 and FT-100 have statistically similar total PM response, the SOF for the two fuels is statistically different. The oxygenated fuel, ADMM15, has a significantly higher soluble organic fraction than FT-100. Whilst FT-100 has a larger portion of insoluble particulate matter. Symkowicz[3] saw a higher fraction of "dry" particulate with FT-100 as part of the Ad Hoc Diesel Fuels Group core program. The ratio of SOF to total particulate may be of interest for determining engine aftertreatment strategies, Figure 12. ADMM15 also has a greater ratio of SOF/PM than both FT-100 and its parent fuel ALS.

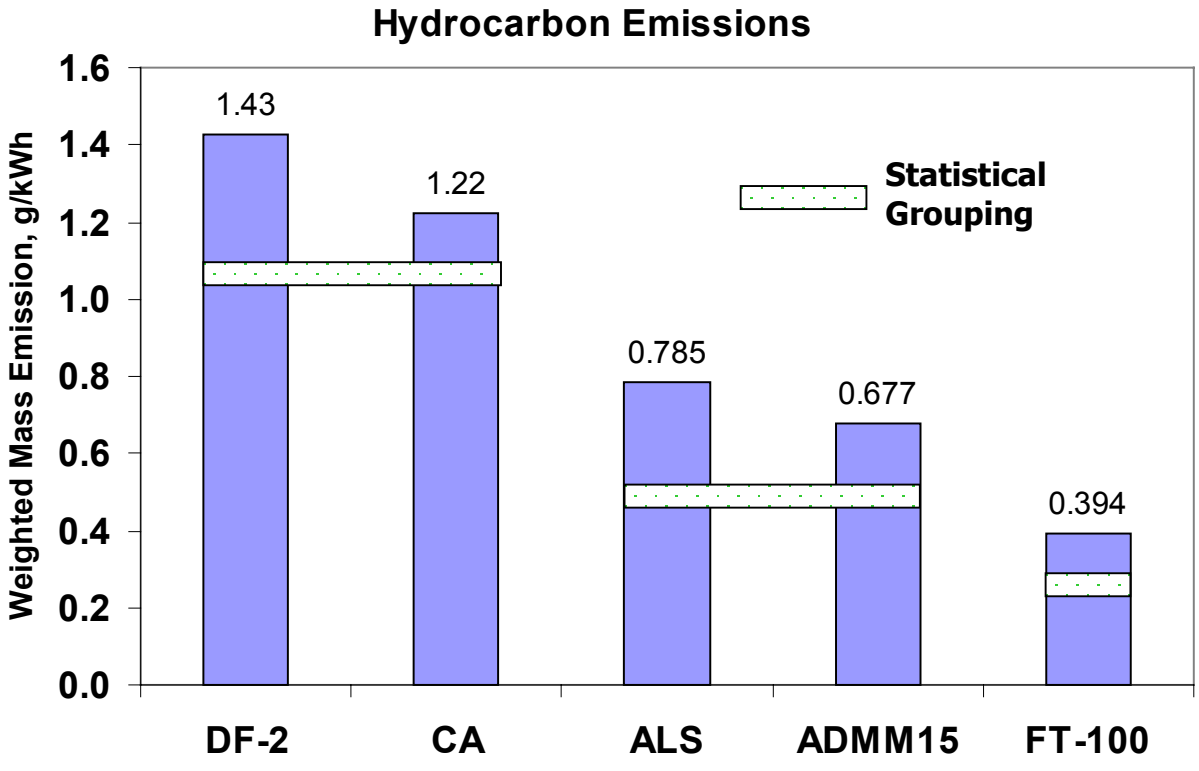


Figure 8. Test Fuel Weighted Average Hydrocarbon Mass Emissions (g/kWh)

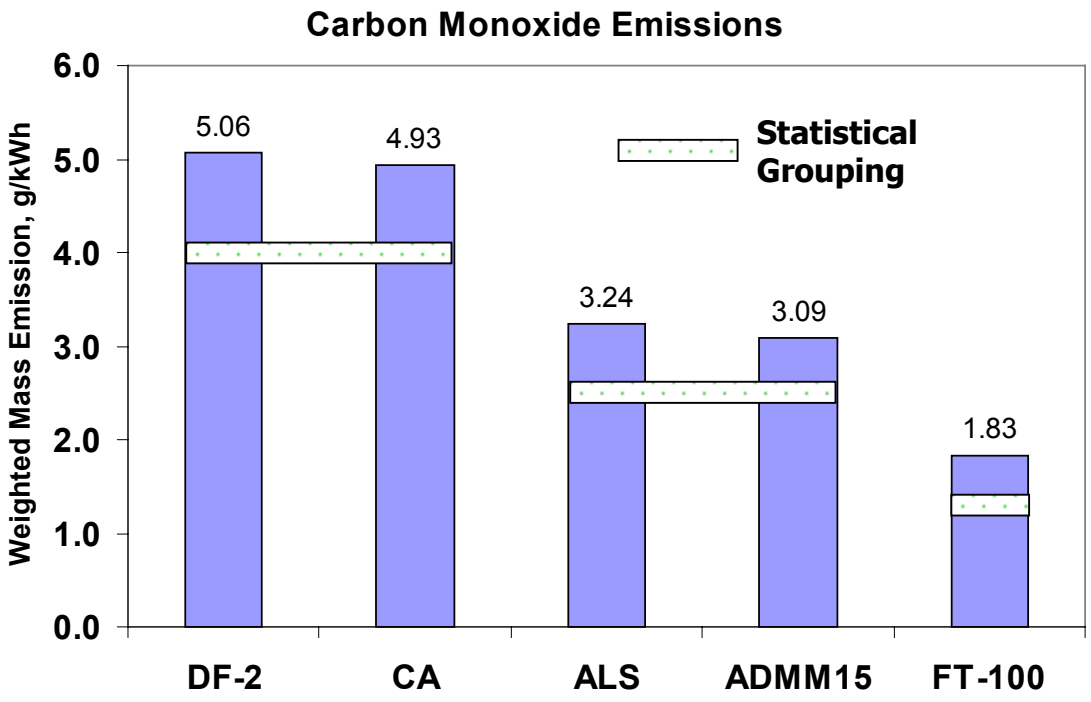


Figure 9. Test Fuel Weighted Average Carbon Monoxide Mass Emissions (g/kWh)

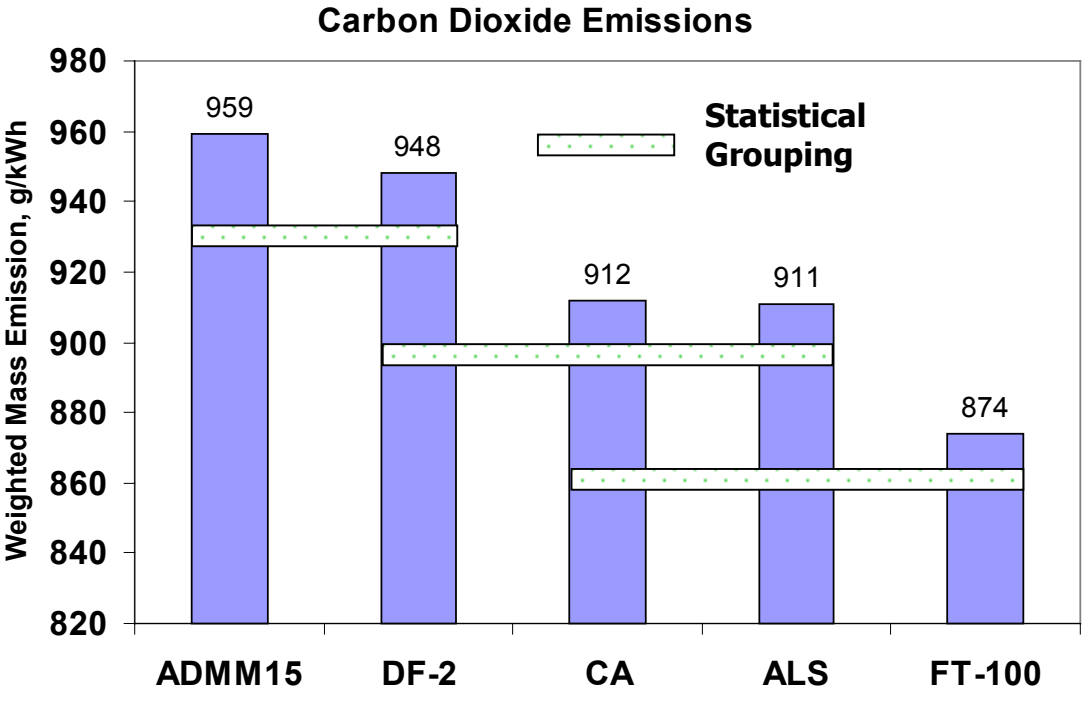


Figure 10. Test Fuel Weighted Average Carbon Dioxide Mass Emissions (g/kWh)

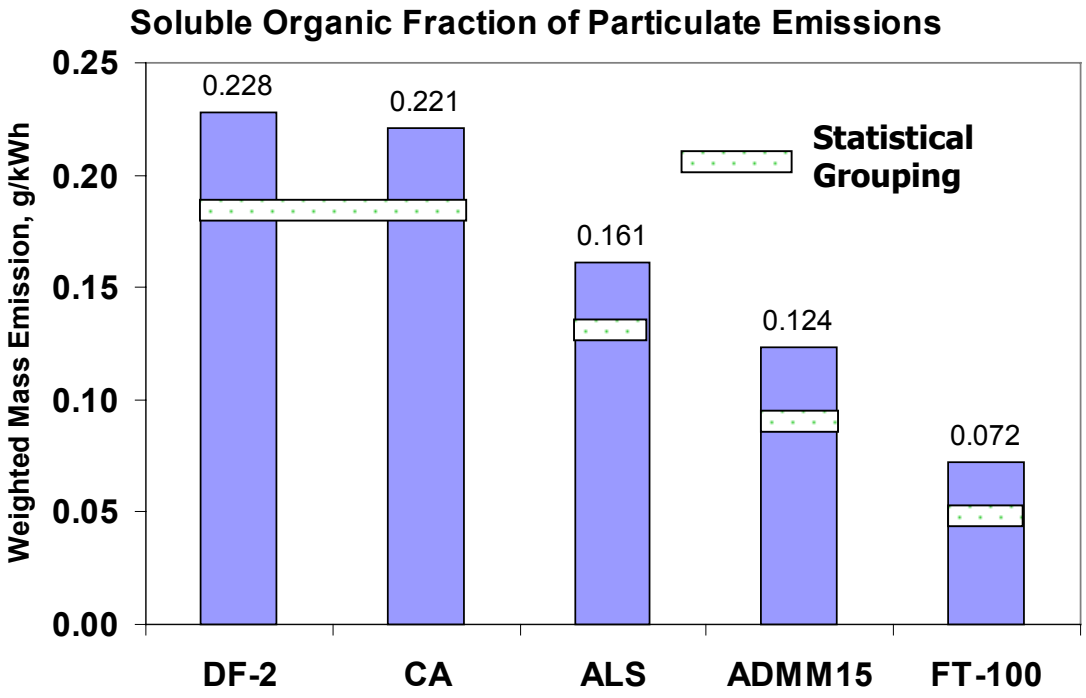


Figure 11. Test Fuel Weighted Average Soluble Organic Fraction of Particulate Mass Emissions (g/kWh)

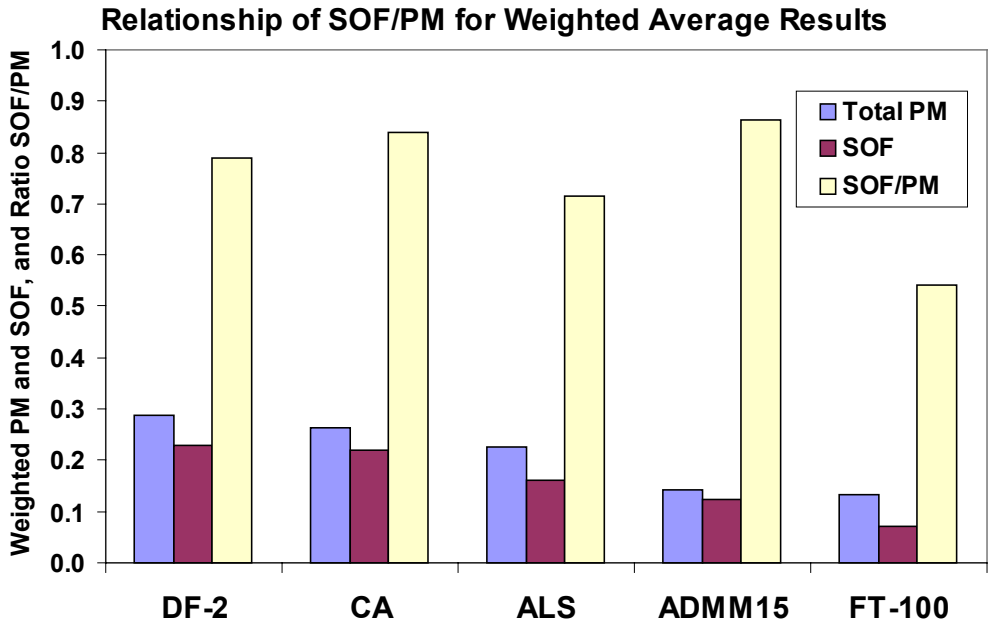


Figure 12. Ratio of SOF to Total PM of Weighted Average Results for Test Fuels

5.2 Fuel Impact on Four Clean Air Act Toxic Air Pollutants

Table 17 is the ranking of the test fuels from the ANOVA for the four EPA Clean Air Act toxic air pollutant compounds. For the EPA toxic air pollutants, ADMM15 and FT-100 were statistically similar emitting fuels, and always in the lowest grouping for the weighted average for LPP operation with pilot fuel injection turned off.

The discussions to follow are summaries of the ANOVA performed for each emission response for the weighted averages, and refer to the results in Table 17. The ANOVA tables for the weighted averages can be found in Appendix C.

Table 17. Clean Air Act Toxic Air Pollutant Compounds Weighted Mass Emissions (mg/kWh) ANOVA Summary for LPP Operation

	LPP Only - Weighted Modes 5,6,10,11		
Response	Fuel	LS Means[1]	Significant Fuel Groups[2]
Benzene	CA	7.297	A
	DF-2	6.360	AB
	ALS	5.017	B
	FT-100	2.504	C
	ADMM15	2.075	C
1,3-Butadiene	CA	6.108	A
	DF-2	5.778	A
	ALS	4.817	AB
	ADMM15	3.921	BC
	FT-100	2.650	C
Formaldehyde	DF-2	484.2	A
	ALS	366.8	AB
	CA	332.4	AB
	ADMM15	267.1	B
	FT-100	206.8	B
Acetaldehyde	DF-2	177.0	A
	ALS	148.8	AB
	CA	126.0	ABC
	ADMM15	92.39	BC
	FT-100	75.01	C

[1]Fuels listed from highest to lowest least squares mean

[2]Letters designate groups of fuel means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

5.2.1 Benzene

The ANOVA for the toxic air pollutant emission benzene revealed statistically significant differences in the average weighted benzene among the fuels. Figure 13 shows the ranking and statistically significant similar groupings (horizontal bars) for benzene emissions. Average weighted benzene at fuels ADMM15 and FT-100 are not significantly different from one another, but are different than the other three fuels. The average weighted benzene at fuel ALS is significantly different than fuel CA. The DF-2 fuel is not significantly different than either the ALS or CA fuel.

5.2.2 1,3-Butadiene

An ANOVA for 1,3-butadiene indicated statistically significant differences exist in the average weighted response among the fuels. For 1,3-butadiene the lowest emitting fuels were FT-100 and ADMM15, then ALS, with the highest emitting fuels being DF-2 and CA; the statistical groupings are shown in Figure 14. The average weighted 1,3-butadiene for the CA and DF-2 fuels are not significantly different from one another, but are significantly different than the ADMM15 and FT-100 fuels. The ADMM15 and FT-100 fuels are not significantly different from one another. Also, the average weighted 1,3-butadiene for the ALS fuel is significantly different than the FT-100 fuel.

5.2.3 Formaldehyde

Statistically significant differences exist in the average weighted formaldehyde emission among the test fuels based on the ANOVA. Figure 15 shows the relative levels and statistical groupings for Formaldehyde emissions. The average weighted formaldehyde for the DF-2 fuel is significantly different than the FT-100 and the ADMM15 fuels.

5.2.4 Acetaldehyde

From ANOVA, statistically significant differences in the average weighted acetaldehyde among the fuels exist. Corresponding groupings for acetaldehyde are shown in Figure 16. The average weighted acetaldehyde for the DF-2 fuel is significantly different than the FT-100 or ADMM15 fuels. The FT-100 and ADMM15 fuels are not significantly different from one another. Also, the average weighted acetaldehyde for the FT-100 fuel is significantly different than the ALS fuel.

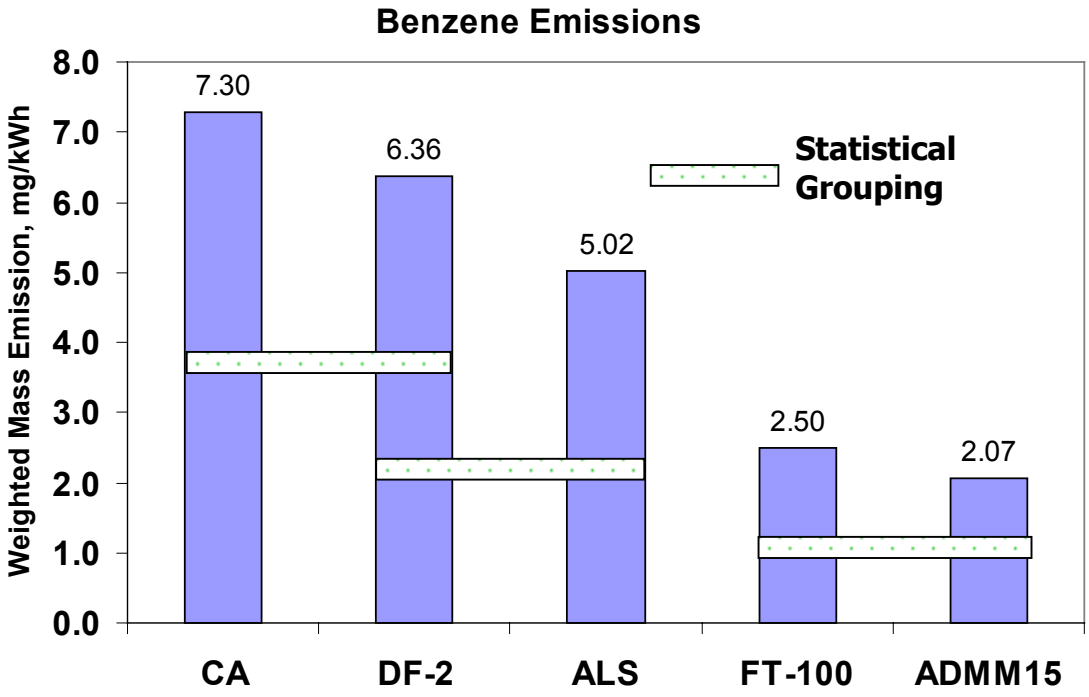


Figure 13. Test Fuel Weighted Average Benzene Mass Emissions (mg/kWh)

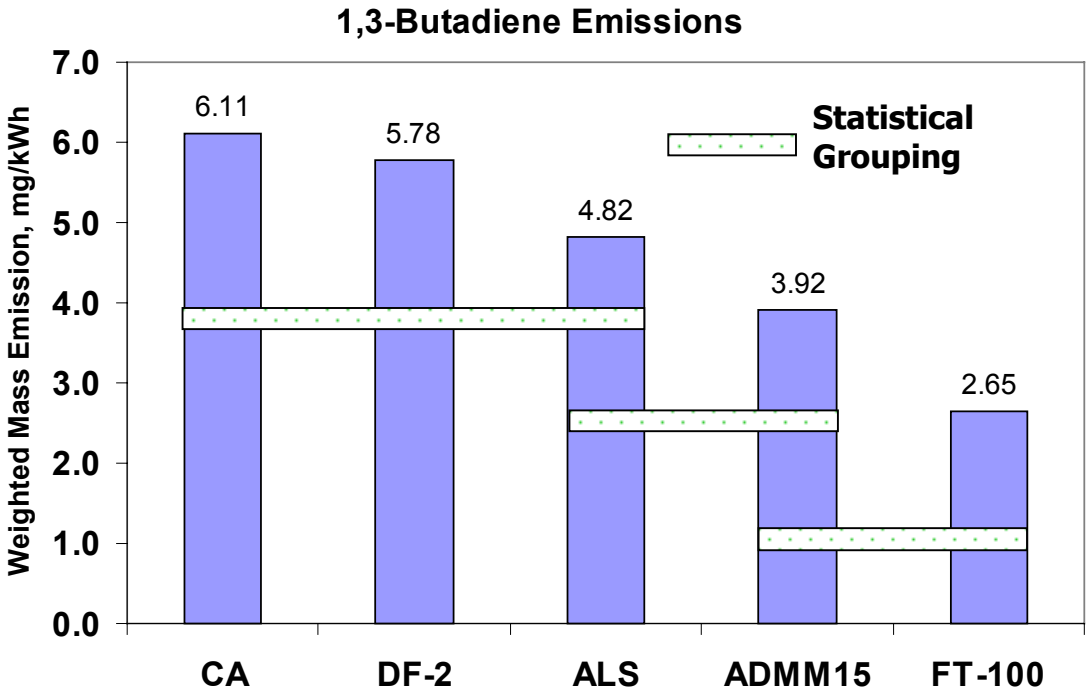


Figure 14. Test Fuel Weighted Average 1,3-Butadiene Mass Emissions (mg/kWh)

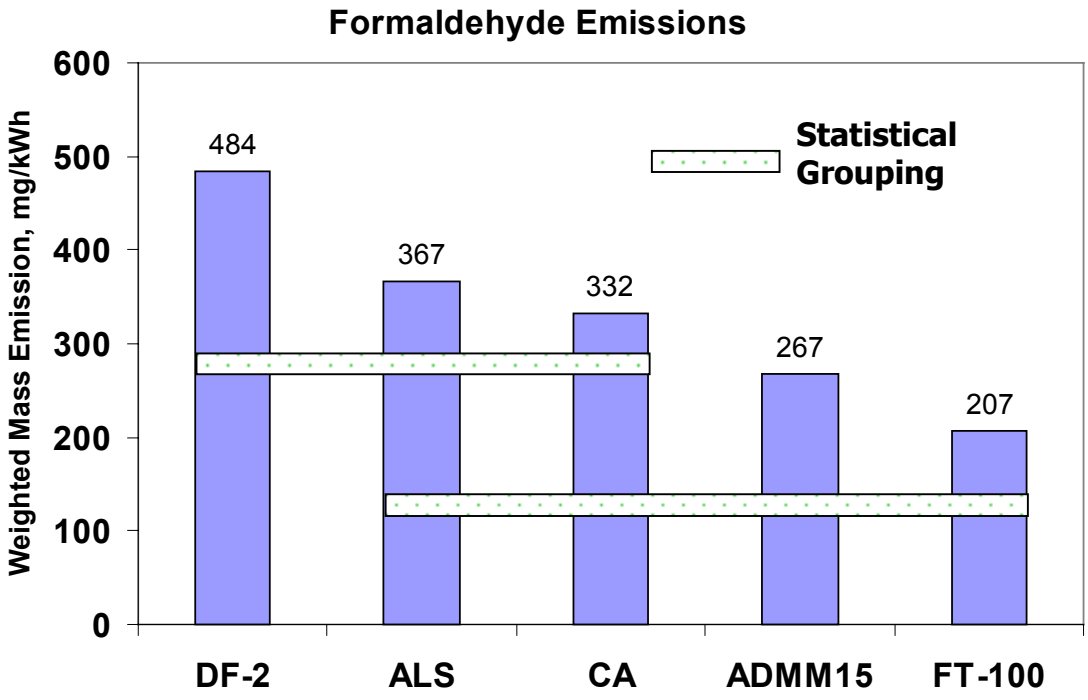


Figure 15. Test Fuel Weighted Average Formaldehyde Mass Emissions (mg/kWh)

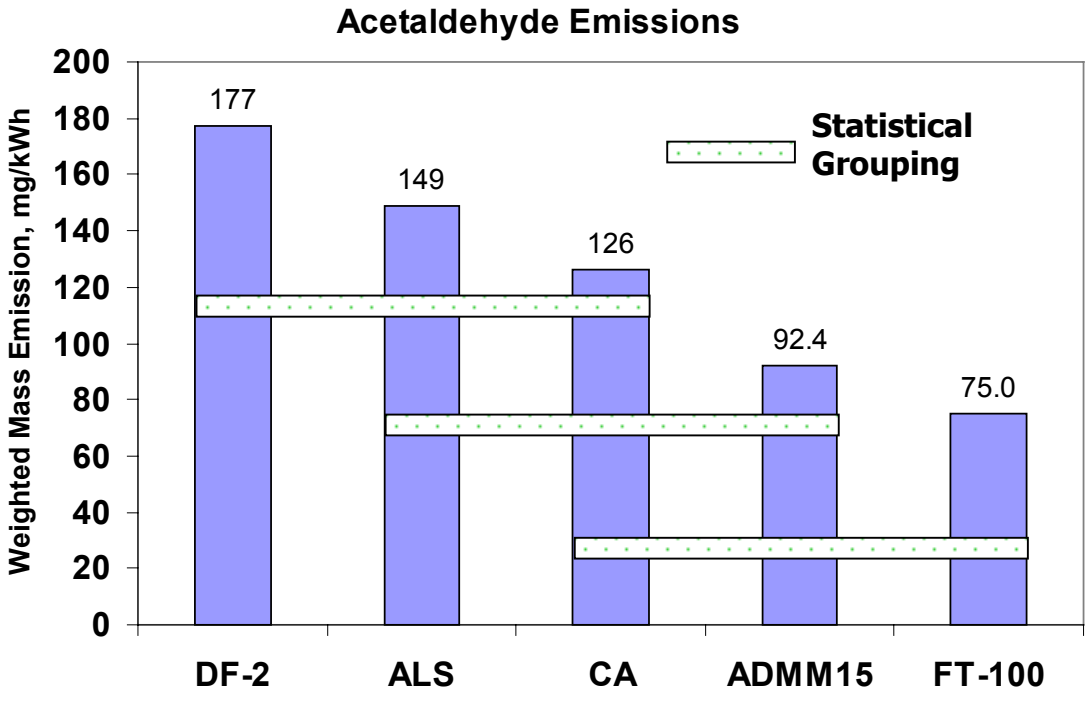


Figure 16. Test Fuel Weighted Average Acetaldehyde Mass Emissions (mg/kWh)

5.3 Fuel Impact on Particulate Soluble Extract PAH Species

The fuel rankings for 13 of the particulate bound soluble phase PAH compounds are shown in Table 18. Due to non-detects, four PAH compounds are being analyzed again with a higher resolution instrument. The four compounds reanalyzed were benzo[a]pyrene, indeno(123-cd)pyrene, dibenzo(a,h)anthracene, and benzo(ghi)perylene. For the majority of PAH compounds DF-2 fuel was statistically different from the other test fuels. The ADMM15 and FT-100 fuels were in the statistically equivalent (95% confidence) lowest grouping for particulate bound PAH compounds.

The discussions to follow are summaries of the ANOVA performed for each emission response for the weighted averages, and refer to the results in Table 18. The ANOVA tables for the weighted averages weighted averages can be found in Appendix C.

Table 18. Weighted Soluble PAH ANOVA Summary for LPP Only Conditions

Response	LPP Only - Weighted Modes 5,6,10,11		
	Fuel	LS Means[1]	Significant Fuel Groups[2]
Naphthalene	DF-2	48.71	A
	CA	46.18	A
	FT-100	39.38	AB
	ADMM15	28.43	AB
	ALS	23.45	B
Acenaphthylene[3]	CA	0.9966	A
	DF-2	0.8074	AB
	FT-100	0.6035	AB
	ADMM15	0.4807	B
	ALS	0.4780	B
Acenaphthene	DF-2	6.564	NS
	CA	5.323	
	FT-100	4.471	
	ADMM15	4.333	
	ALS	2.314	
Fluorene[3]	DF-2	12.49	A
	CA	9.226	AB
	ADMM15	7.173	B
	FT-100	6.208	B
	ALS	4.214	B
Phenanthrene	DF-2	103.0	A
	CA	72.85	AB
	FT-100	43.01	B
	ALS	36.00	B
	ADMM15	29.81	B
Anthracene	DF-2	4.197	A
	CA	4.161	A
	FT-100	2.920	AB
	ADMM15	2.287	BC
	ALS	0.7376	C

Table 18. Weighted Soluble PAH ANOVA Summary for LPP Only Conditions (contd)			
Response	**LPP Only - Weighted Modes 5,6,10,11**		
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**
Fluoranthene	DF-2	51.19	A
	ALS	19.54	B
	CA	17.78	B
	FT-100	15.48	B
	ADMM15	9.829	B
Pyrene	DF-2	83.53	A
	ALS	21.30	B
	CA	13.67	B
	FT-100	12.71	B
	ADMM15	9.984	B
Benzo[a]anthracene	DF-2	2.455	A
	CA	1.063	B
	ALS	0.7125	BC
	FT-100	0.2531	BC
	ADMM15	0.1550	C
Chrysene	DF-2	7.735	A
	CA	2.391	B
	ALS	1.936	B
	FT-100	0.7735	B
	ADMM15	0.5860	B
Benzo[b]fluoranthene[3]	DF-2	1.538	A
	ALS	1.253	A
	CA	1.190	A
	ADMM15	0.3893	B
	FT-100	0.3046	B
Benzo[k]fluoranthene	DF-2	2.291	A
	CA	1.189	B
	ALS	0.6576	B
	ADMM15	0.4236	B
	FT-100	0.3539	B
Benzo[e]pyrene[3]	DF-2	1.059	A
	CA	0.6799	AB
	ALS	0.6206	AB
	FT-100	0.2671	B
	ADMM15	0.2101	B
Benzo[a]pyrene	ALS	0.4346	A
	CA	0.3467	AB
	DF-2	0.2002	BC
	FT-100	0.0684	C
	ADMM15	0.0548	C
Indeno(1,2,3-cd)pyrene	DF-2	0.3978	A
	ADMM15	0.0731	B
	FT-100	0.0613	B
Benzo[ghi]perylene	CA	0.7062	A
	DF-2	0.6439	A
	ADMM15	0.2085	B
	FT-100	0.1541	B

[1]Fuels listed from highest to lowest least squares mean

[2]Letters designate groups of fuel means within which there are no statistically significant differences

[3]Some fuel data were imputed in the calculation of the weighted response because of non-detects

NS = no statistically significant differences in the mean response at the 5% level of significance

5.3.1 Naphthalene

The ANOVA revealed statistically significant differences in the average naphthalene among the fuels. Figure 17 shows the statistical groupings for the PAH naphthalene bound to the particulate matter. The average weighted naphthalene for the ALS fuel is significantly different from the CA and DF-2 fuels.

5.3.2 Acenaphthylene

The ANOVA for acenaphthylene revealed statistically significant differences in the average weighted acenaphthylene among the fuels. Some fuel data were imputed in the calculation of the weighted response because of non-detects for various modes and fuels. The data was imputed utilizing the detection limits. The weighted average acenaphthylene response, and the statistical groups are shown in Figure 18. The average weighted acenaphthylene for the CA fuel is significantly different from the ADMM15 and ALS fuels.

5.3.3 Acenaphthene

The weighted average acenaphthene response is shown in Figure 19. From ANOVA statistically significant differences did not exist in the average acenaphthene among the test fuels.

5.3.4 Fluorene

The ANOVA showed statistically significant differences in the average weighted fluorene among the fuels. Some ALS fuel data was imputed for repeat runs because of non-detects in modes 5 and 11. The average weighted fluorene for the DF-2 fuel is significantly different from the ADMM15, FT-100, and ALS fuels. Figure 20 shows the weighted average fluorene and the statistical groups.

5.3.5 Phenanthrene

A statistically significant difference in the average weighted phenanthrene response exists among the test fuels. The phenanthrene response is shown in Figure 21. The average weighted phenanthrene for the DF-2 fuel is significantly different than the ADMM15, ALS, and FT-100 fuels. The average weighted phenanthrene for the ADMM15, ALS, FT-100, and CA fuels are not significantly different from one another.

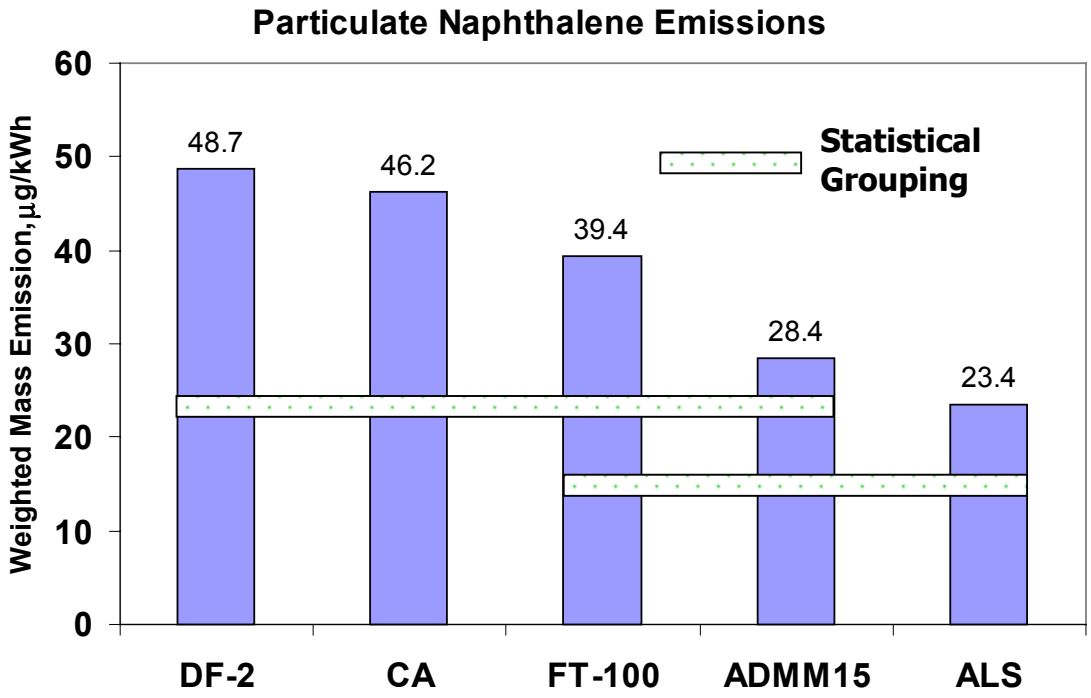


Figure 17. Test Fuel Weighted Average Particulate Phase Naphthalene Mass Emissions (µg/kWh)

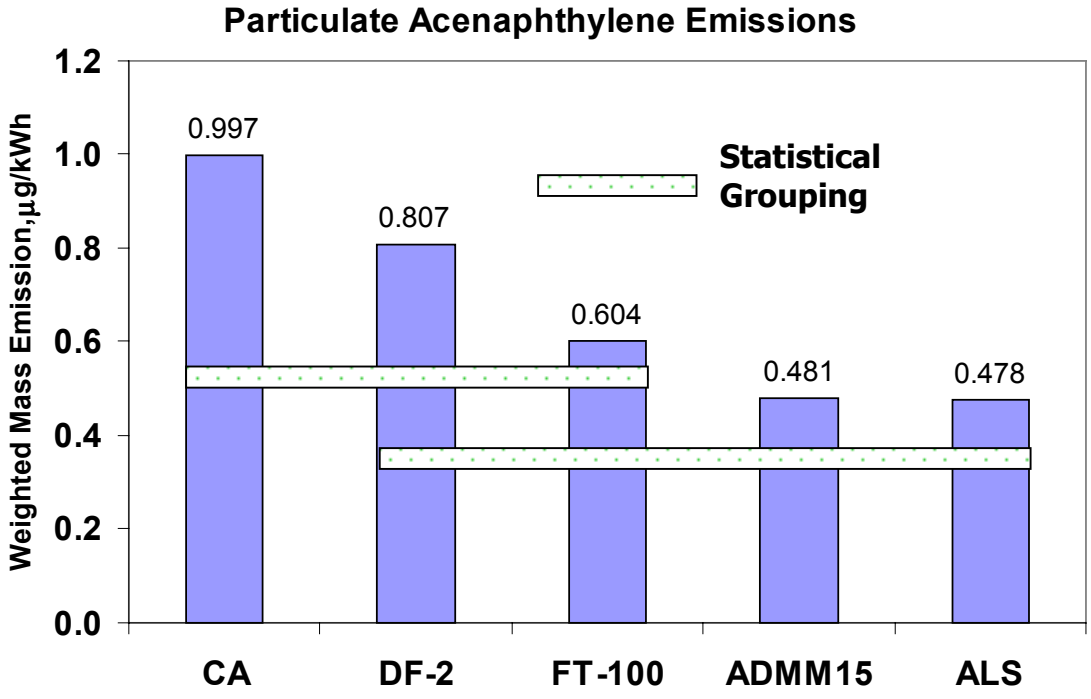


Figure 18.Test Fuel Weighted Average Particulate Phase Acenaphthylene Mass Emissions (µg/kWh)

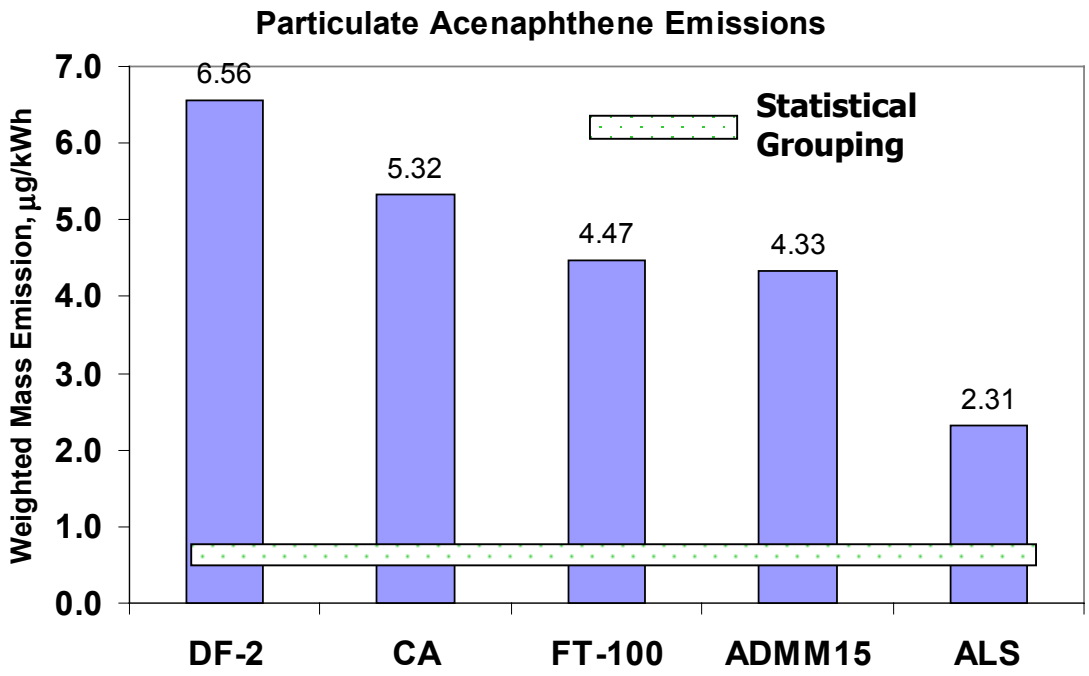


Figure 19. Test Fuel Weighted Average Particulate Phase Acenaphthene Mass Emissions (µg/kWh)

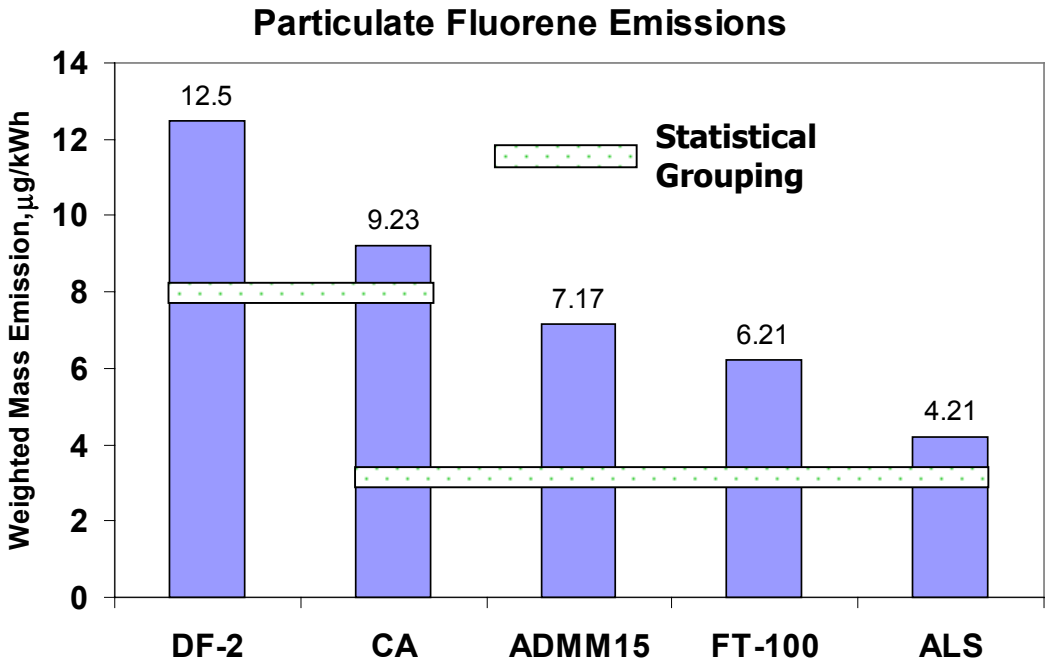


Figure 20. Test Fuel Weighted Average Particulate Phase Fluorene Mass Emissions (µg/kWh)

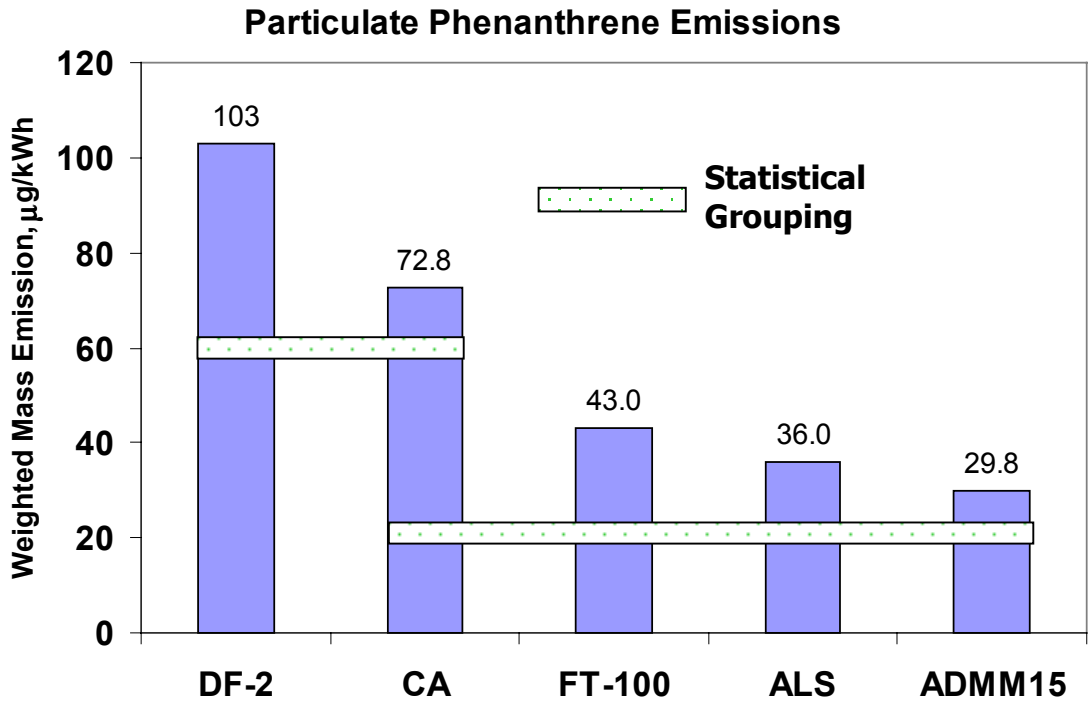


Figure 21. Test Fuel Weighted Average Particulate Phase Phenanthrene Mass Emissions (µg/kWh)

5.3.6 Anthracene

From ANOVA a statistically significant difference in the average weighted anthracene is revealed among the fuels. The weighted average results for anthracene are shown in Figure 22. The average weighted anthracene for the ALS fuel is significantly different from the CA, DF-2, and FT-100 fuels. Also, the ADMM15 fuel has a significantly different weighted anthracene than the CA and DF-2 fuels.

5.3.7 Fluoranthene

Statistically significant differences exist in the average weighted fluoranthene response among the fuels. The average weighted fluoranthene for the DF-2 fuel is significantly different from the remaining four fuels. The ADMM15, FT-100, CA, and ALS fuels are not significantly different from one another with respect to the average weighted fluoranthene, Figure 23.

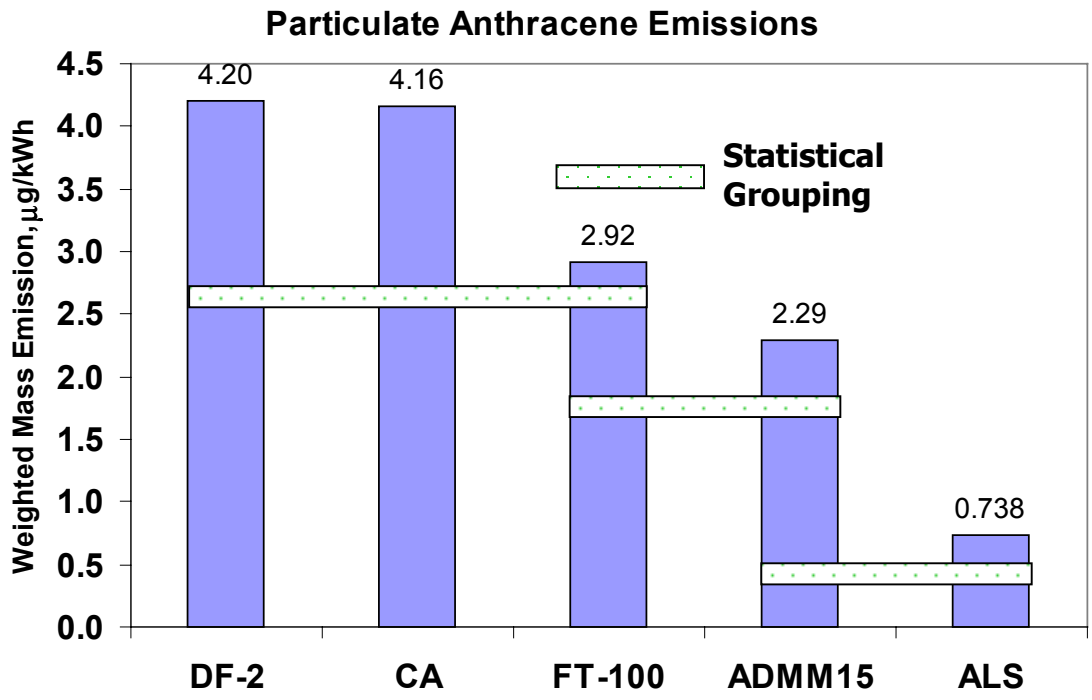


Figure 22. Test Fuel Weighted Average Particulate Phase Anthracene Mass Emissions (µg/kWh)

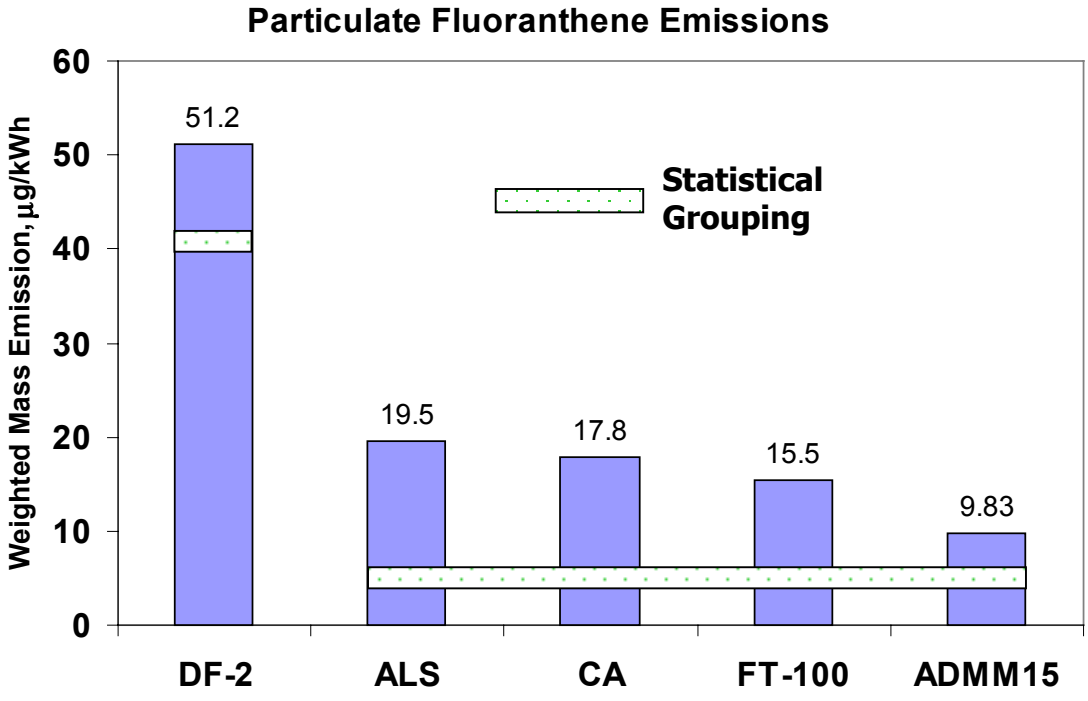


Figure 23. Test Fuel Weighted Average Particulate Phase Fluoranthene Mass Emissions (µg/kWh)

5.3.8 Pyrene

The average weighted pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The pyrene results are shown in Figure 24. The ADMM15, FT-100, CA, and ALS fuels are not significantly different from one another with respect to the average weighted pyrene.

5.3.9 Benzo[a]anthracene

The ANOVA for benzo[a]anthracene, levels shown in Figure 25, indicated there were statistically significant differences in the average weighted benzo[a]anthracene among the fuels. The average weighted benzo[a]anthracene for the DF-2 fuel is significantly different than the remaining four fuels. Also, the average weighted benzo[a]anthracene for the CA fuel is significantly different than the ADMM15 fuel.

5.3.10 Chrysene

There were statistically significant differences in the average weighted chrysene for the test fuels. Figure 26 is the statistical groupings for the particulate phase PAH chrysene. The average weighted chrysene for the DF-2 fuel is significantly different than the remaining four fuels. The ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another with respect to the average weighted chrysene.

5.3.11 Benzo[b]fluoranthene

The ANOVA for the PAH benzo[b]fluoranthene has shown statistically significant differences in the average weighted benzo[b]fluoranthene among the fuels. Some of the CA fuel data was imputed for the analysis due to non-detects in modes 5 and 11. The results are depicted in Figure 27. There are two distinct fuel groupings with respect to the average weighted benzo[b]fluoranthene. The ADMM15 and FT-100 fuels are not significantly different from one another, but are different from the remaining three fuels. The ALS, CA, and DF-2 fuels are not significantly different from one another.

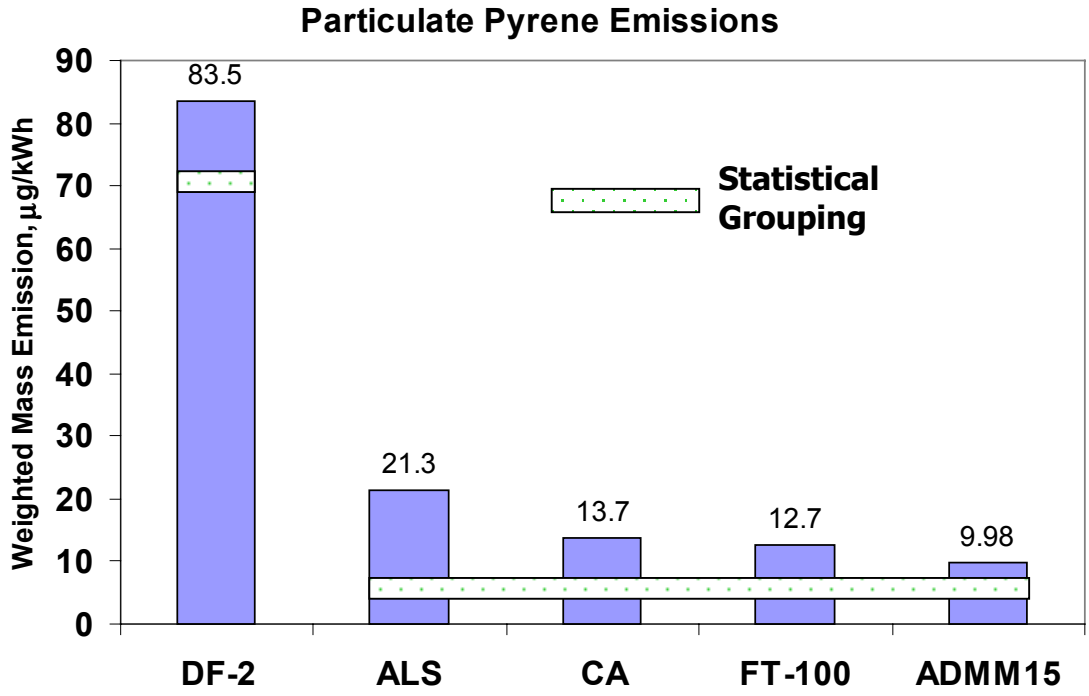


Figure 24. Test Fuel Weighted Average Particulate Phase Pyrene Mass Emissions (µg/kWh)

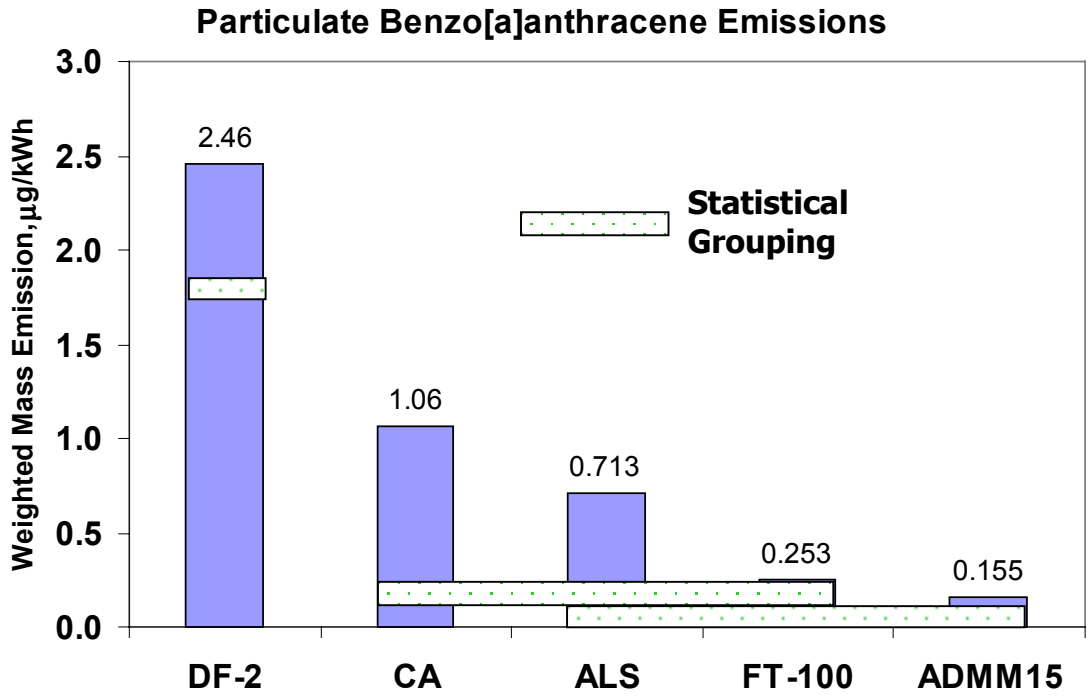


Figure 25. Test Fuel Weighted Average Particulate Phase Benzo[a]anthracene Mass Emissions (µg/kWh)

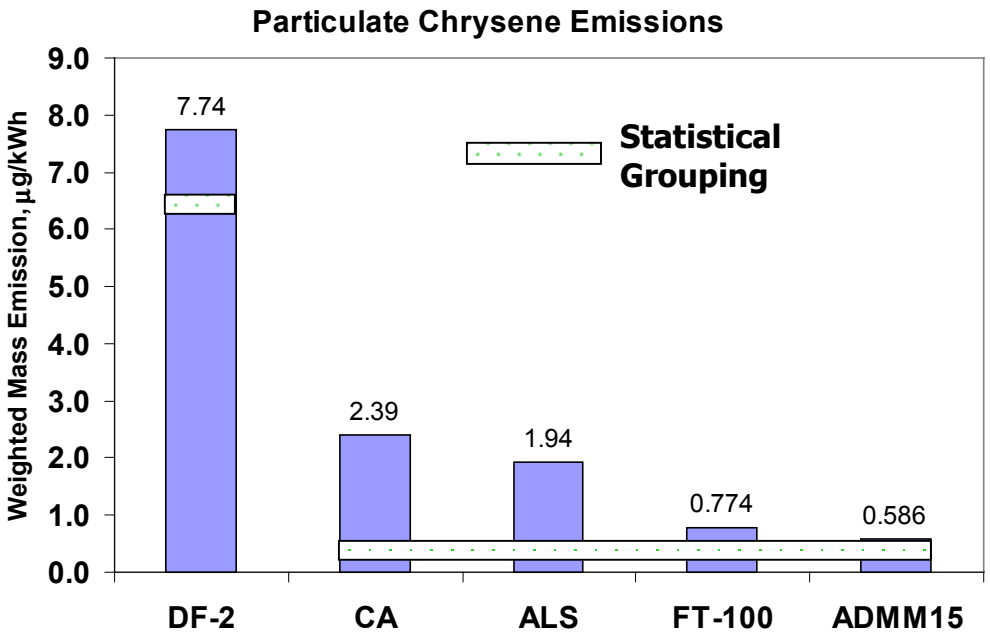


Figure 26. Test Fuel Weighted Average Particulate Chrysene Mass Emissions

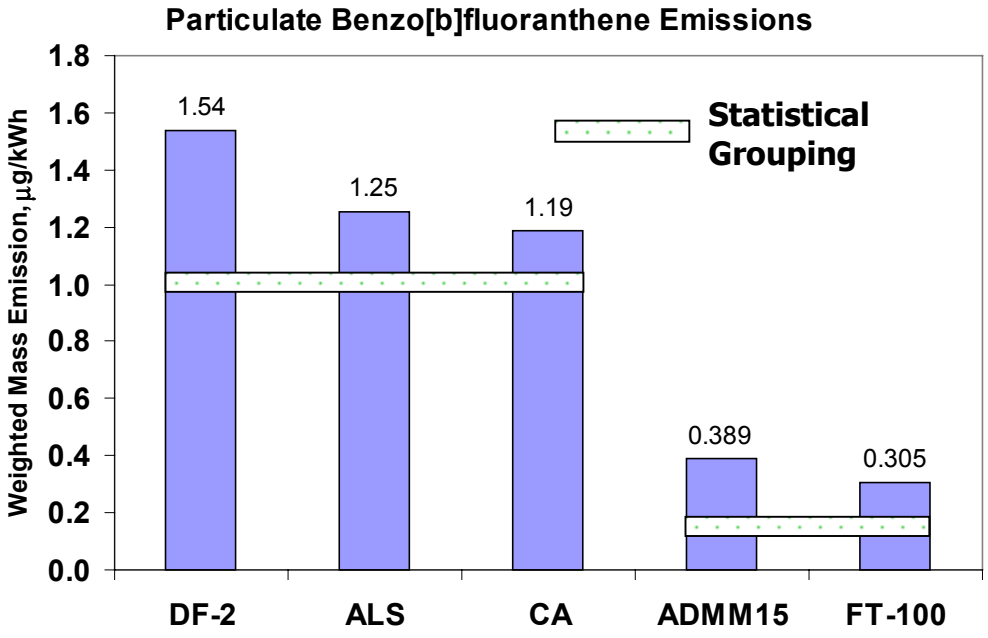


Figure 27. Test Fuel Weighted Average Particulate Phase Benzo[b]fluoranthene Mass Emissions (µg/kWh)

5.3.12 Benzo[k]fluoranthene

Average weighted benzo[k]fluoranthene response had statistically significant differences among the fuels. The least-square means and groups are shown in Figure 28 for benzo[k]fluoranthene. The average weighted benzo[k]fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another with respect to the average weighted benzo[k]fluoranthene.

5.3.13 Benzo[e]pyrene

For the ANOVA for benzo[e]pyrene, statistically significant differences were seen in the average weighted benzo[e]pyrene among the fuels. Some DF-2 data was imputed for repeat runs because of non-detects in modes 5 and 6. The emissions of particulate bound PAH benzo[e]pyrene is shown in Figure 29, along with the statistical groupings. The average weighted benzo[e]pyrene for the DF-2 fuel is significantly different than the ADMM15 and FT-100 fuels.

5.3.14 Benzo[a]pyrene

Due to non-detects for benzo[a]pyrene using high-resolution GC/ low-resolution MS, the extracts were reanalyzed utilizing a high-resolution MS detector. The selection criteria for reanalysis was any non-idle modal LPP experiment that did not have a benzo[a]pyrene result with the low-resolution instrument. The ANOVA for benzo[a]pyrene revealed statistically significant differences in the average benzo[a]pyrene response among the fuels. The emissions of particulate bound PAH benzo[e]pyrene are shown in Figure 30, along with the statistical groupings. The average weighted benzo[a]pyrene for the ADMM15 and FT-100 fuels is significantly different than the CA and ALS fuels. Also, ALS fuel has a significantly different weighted benzo[a]pyrene than the DF-2 fuel.

5.3.15 Indeno(1,2,3-cd)pyrene

High-resolution analysis of the extracts were also performed for the PAH indeno(1,2,3-cd)pyrene. Statistically significant differences were seen in the average weighted indeno(1,2,3-cd)pyrene among the fuels, and the results are shown in Figure 31. Figure 31 does not have results for ALS or CA fuels due to the number of non-detects that made analysis meaningless. The average indeno(1,2,3-cd)pyrene for the ADMM15 and FT-100 fuels are not significantly different from one another, but both are significantly different from the DF-2 fuel.

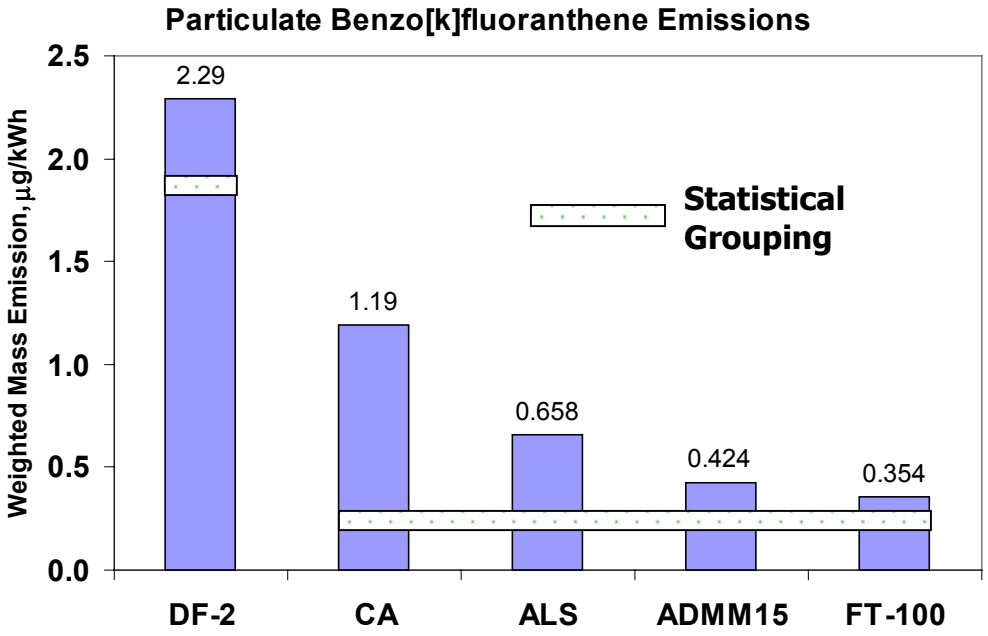


Figure 28. Test Fuel Weighted Average Particulate Phase Benzo[k]fluoranthene Mass Emissions (µg/kWh)

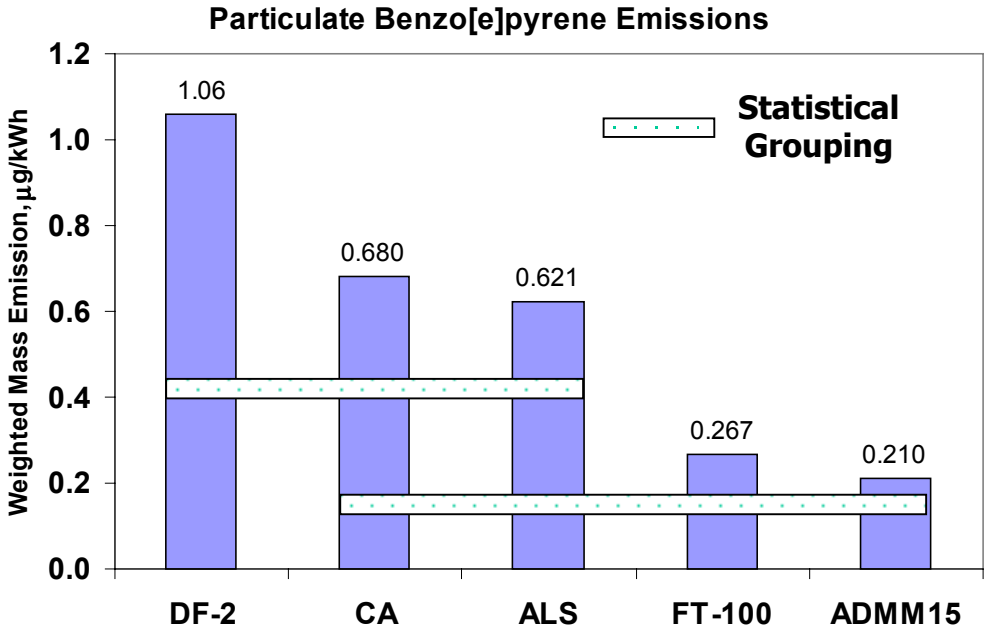


Figure 29. Test Fuel Weighted Average Particulate Phase Benzo(e)pyrene Mass Emissions (µg/kWh)

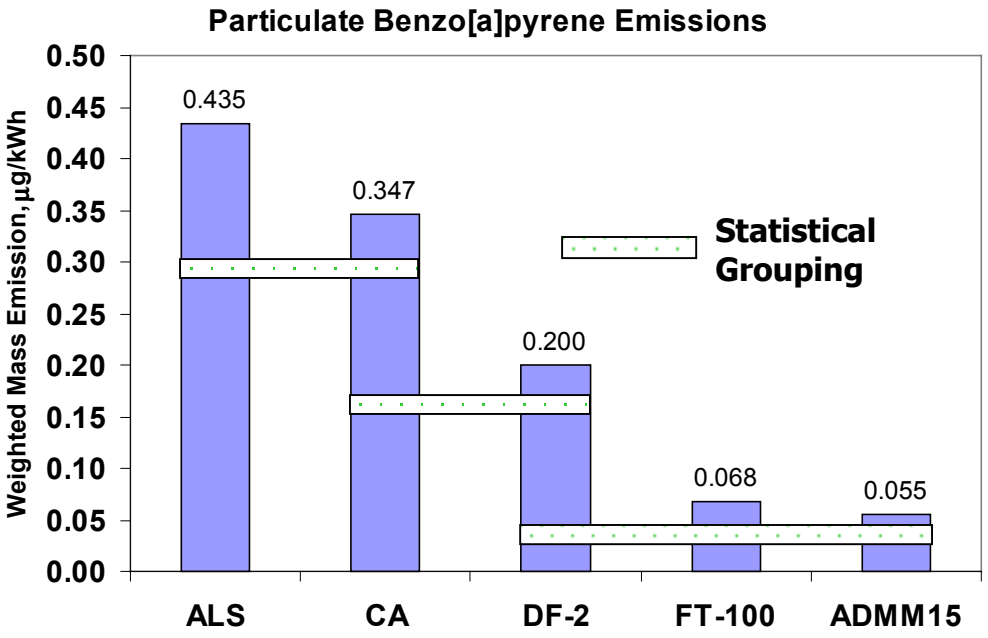


Figure 30. Test Fuel Weighted Average Particulate Phase Benzo[a]pyrene Mass Emissions (µg/kWh)

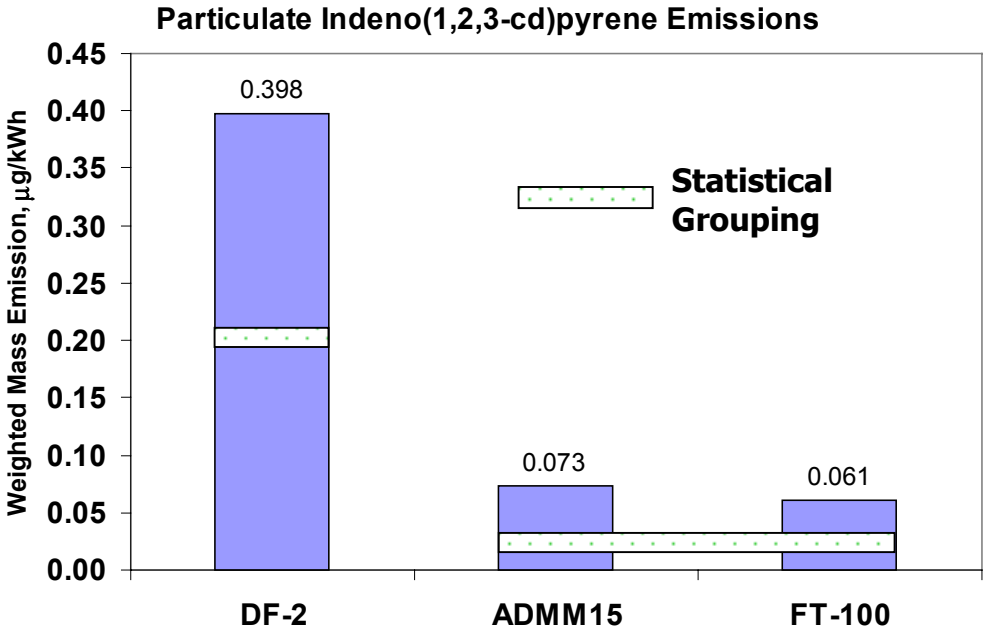


Figure 31. Test Fuel Weighted Average Particulate Phase Indeno(1,2,3-cd)pyrene Mass Emissions (µg/kWh)

5.3.16 Dibenzo[a,h]anthracene

Although high-resolution analysis was attempted on this PAH species, sufficient non-detects existed such that the weighted averaging could not be performed in a meaningful manner.

5.3.17 Benzo[ghi]perylene

High-resolution analysis of the extracts were also performed for the PAH benzo[ghi]perylene. Statistically significant differences were seen in the average weighted benzo[ghi]perylene among the fuels, and the results are shown in Figure 32. The average benzo[ghi]perylene for the FT-100 and ADMM15 fuels are significantly different from the DF-2 and CA fuels, but not significantly different from one another. Also, the DF-2 and CA fuels are not significantly different from one another.

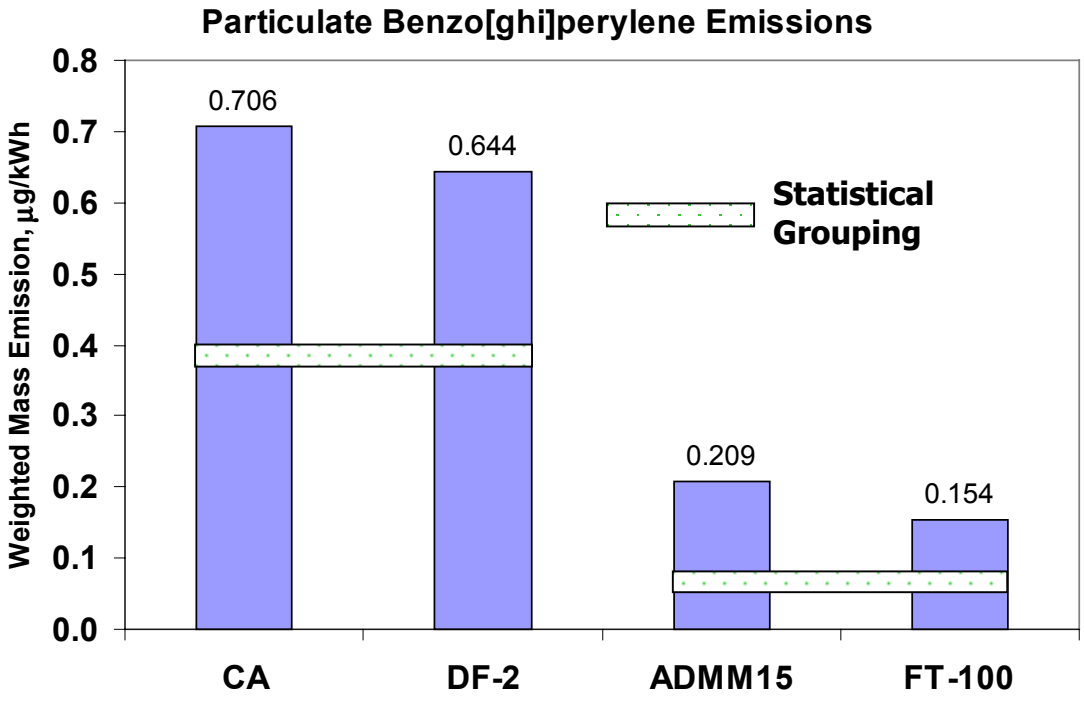


Figure 32. Test Fuel Weighted Average Particulate Phase Benzo[ghi]perylene Mass Emissions (µg/kWh)

5.4 Fuel Impact on Gaseous PAH Species

The gas phase PAH emissions rank the test fuels in the general order shown in Table 19. Included in Table 19 are the least-square means from the ANOVA, along with the statistically significant groupings for the weighted average mass emissions. The general trends were for DF-2 to have the highest gas phase PAH emissions, while ADMM15 and FT-100 always had the statistically lowest PAH emissions. The ANOVA for gas phase PAH species indicated the oxygenated diesel fuel, ADMM15, was statistically equivalent to FT-100.

The discussions to follow are summaries of the ANOVA performed for each emission response for the weighted averages, and refer to the results in Table 19. The ANOVA tables for the weighted averages can be found in Appendix C.

Table 19. Weighted Gaseous PAH ANOVA Summary for LPP Only Conditions

Response	LPP Only - Weighted Modes 5,6,10,11		
	Fuel	LS Means[1]	Significant Fuel Groups[2]
Naphthalene	CA	5436	A
	DF-2	3226	B
	ALS	1127	C
	ADMM15	467.1	C
	FT-100	252.5	C
2-Methylnaphthalene	DF-2	4750	A
	CA	3065	B
	ALS	737.3	C
	ADMM15	238.8	C
	FT-100	113.9	C
1-Methylnaphthalene	DF-2	3268	A
	CA	1713	B
	ALS	409.9	C
	ADMM15	111.1	C
	FT-100	65.72	C
2,6-Dimethylnaphthalene	DF-2	3462	A
	CA	722.3	B
	ALS	242.3	B
	ADMM15	48.81	B
	FT-100	44.71	B
Acenaphthylene	DF-2	324.8	A
	ALS	122.2	B
	CA	102.2	B
	ADMM15	46.44	B
	FT-100	45.21	B
Acenaphthene	DF-2	517.5	A
	CA	75.37	B
	ALS	37.61	B
	ADMM15	19.14	B
	FT-100	8.501	B

Table 19. Weighted Gaseous PAH ANOVA Summary for LPP Only Conditions (contd)			
	LPP Only - Weighted Modes 5,6,10,11		
Response	Fuel	LS Means[1]	Significant Fuel Groups[2]
Fluorene	DF-2	931.9	A
	CA	108.6	B
	ALS	45.82	B
	FT-100	15.91	B
	ADMM15	15.54	B
Phenanthrene	DF-2	1586	A
	CA	199.5	B
	ALS	120.1	B
	FT-100	40.99	B
	ADMM15	35.57	B
Anthracene	DF-2	51.59	A
	CA	9.235	B
	ALS	5.364	B
	ADMM15	1.954	B
	FT-100	1.676	B
Fluoranthene	DF-2	13.22	A
	CA	3.921	B
	ALS	3.295	B
	FT-100	1.870	B
	ADMM15	1.454	B
Pyrene	DF-2	17.54	A
	CA	3.137	B
	ALS	2.838	B
	FT-100	1.406	B
	ADMM15	1.142	B
[1]Fuels listed from highest to lowest least squares mean			
[2]Letters designate groups of fuel means within which there are no statistically significant differences			
NS = no statistically significant differences in the mean response at the 5% level of significance			

5.4.1 Naphthalene

Statistically significant differences were noted in the average weighted gas phase naphthalene among the fuels. The gas phase PAH naphthalene mass emissions are shown in Figure 33 along with the statistical groupings. There are three distinct fuel groupings with respect to the average weighted naphthalene. FT-100, ADMM15, and ALS fuels are not significantly different from one another, but they are significantly different from the other two fuels. The DF-2 and CA fuels are significantly different from one another and the remaining three fuels.

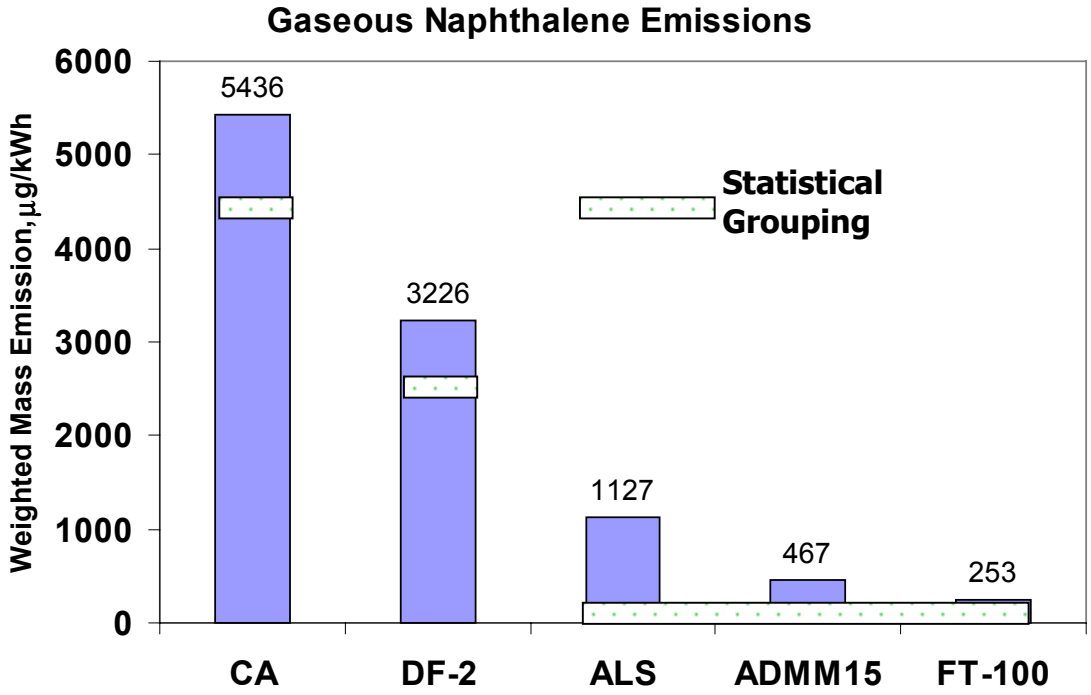


Figure 33. Test Fuel Weighted Average Gaseous Phase Naphthalene Mass Emissions (µg/kWh)

5.4.2 2-Methylnaphthalene

Statistically significant differences in the average weighted 2-methylnaphthalene among the fuels are shown in Figure 34. There are three distinct fuel groupings with respect to the average weighted 2-methylnaphthalene. FT-100, ADMM15, and ALS fuels are not significantly different from one another, but they are significantly different from the other two fuels. The DF-2 and CA fuels are significantly different from one another and the remaining three fuels.

5.4.3 1-Methylnaphthalene

The ANOVA for 1-methylnaphthalene showed statistically significant differences in the average weighted 1-methylnapthalene among the fuels. There are three distinct fuel groupings with respect to the average weighted 1-methylnaphthalene as shown in Figure 35. FT-100, ADMM15, and ALS fuels are not significantly different from one another, but they are significantly different from the other two fuels. The DF-2 and CA fuels are significantly different from one another and the remaining three fuels.

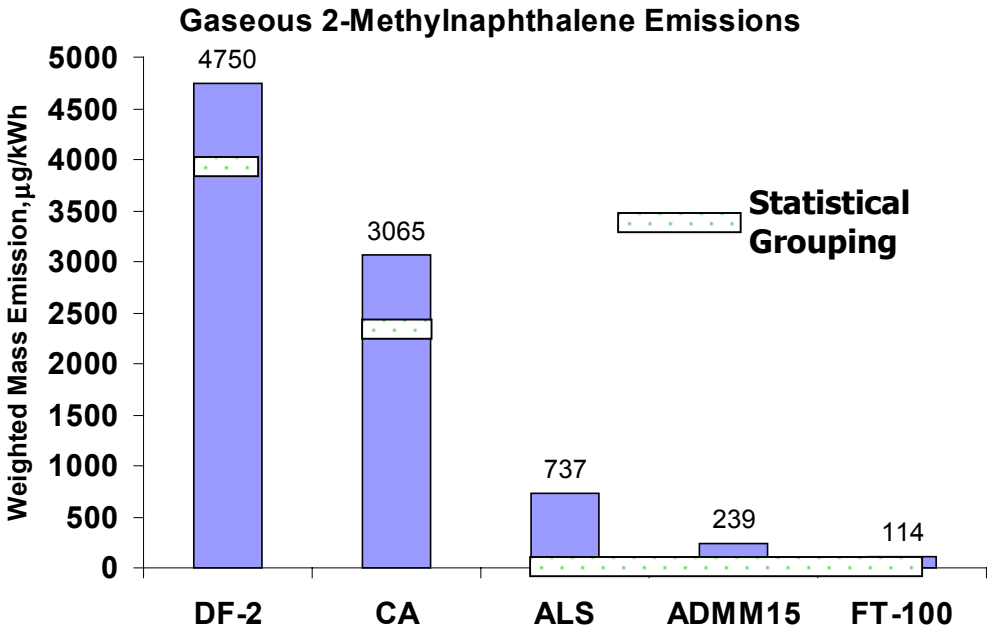


Figure 34. Test Fuel Weighted Average Gaseous Phase 2-Methylnaphthalene Mass Emissions (µg/kWh)

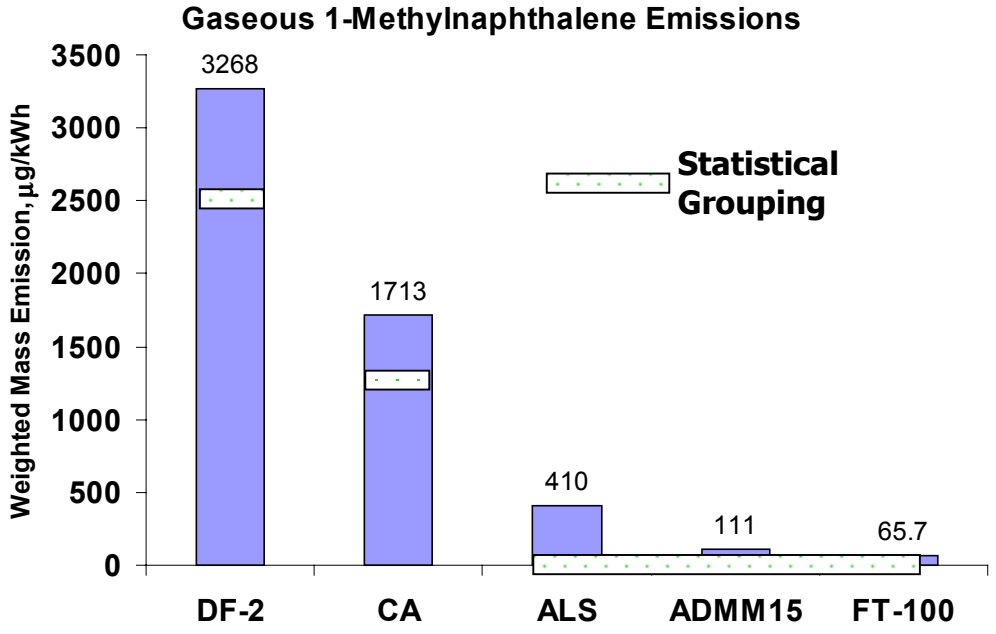


Figure 35. Test Fuel Weighted Average Gaseous Phase 1-Methylnaphthalene Mass Emissions (µg/kWh)

5.4.4 2,6-Dimethylnaphthalene

Statistically significant differences in the average weighted 2,6-dimethylnaphthalene are shown in Figure 36. The average weighted 2,6-dimethylnaphthalene for the DF-2 fuel is significantly different than the other four fuels. The average weighted 2,6-dimethylnaphthalene among the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another.

5.4.5 Acenaphthylene

Figure 37 shows the average weighted acenaphthylene for the DF-2 fuel is significantly different than the other four fuels. The average weighted acenaphthylene among the FT-100, ADMM15, CA, and ALS fuels are not significantly different from one another.

5.4.6 Acenaphthene

The average weighted acenaphthene for the DF-2 fuel is significantly different than the other four fuels. The average weighted acenaphthene among the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another. The relative response is shown in Figure 38 for the gas phase PAH acenaphthene.

5.4.7 Fluorene

The statistically significant differences in the average weighted fluorene among the fuels is shown in Figure 39. The average weighted fluorene for the DF-2 fuel is significantly different than the other four fuels. The average weighted fluorene among the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

5.4.8 Phenanthrene

Shown in Figure 40, the average weighted phenanthrene for the DF-2 fuel is significantly different than the other four fuels. The average weighted phenanthrene among the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

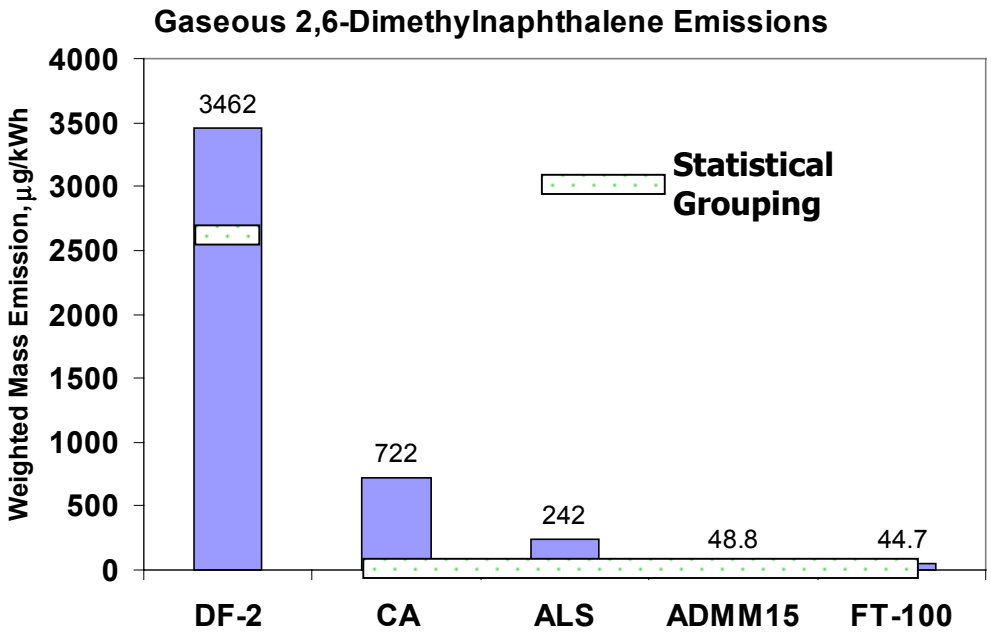


Figure 36. Test Fuel Weighted Average Gaseous Phase 2,6-Dimethylnaphthalene Mass Emissions (µg/kWh)

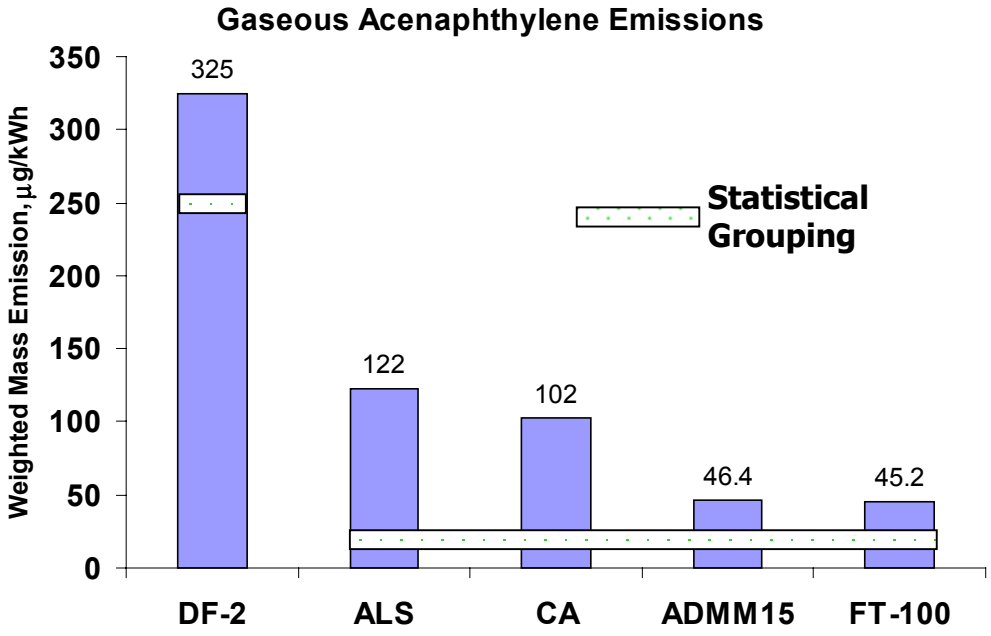


Figure 37. Test Fuel Weighted Average Gaseous Phase Acenaphthylene Mass Emissions (µg/kWh)

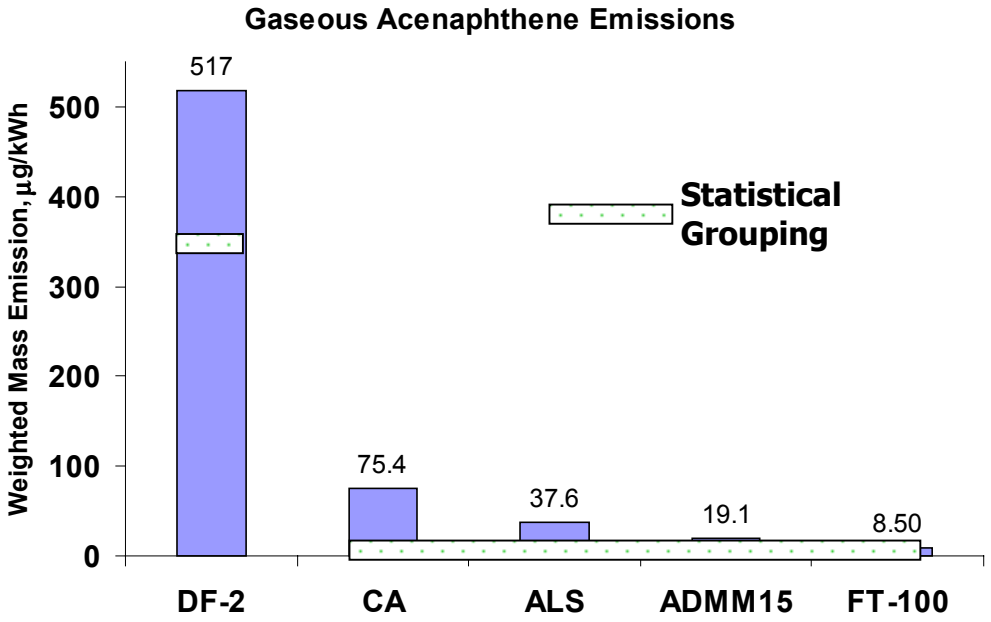


Figure 38. Test Fuel Weighted Average Gaseous Phase Acenaphthene Mass Emissions (µg/kWh)

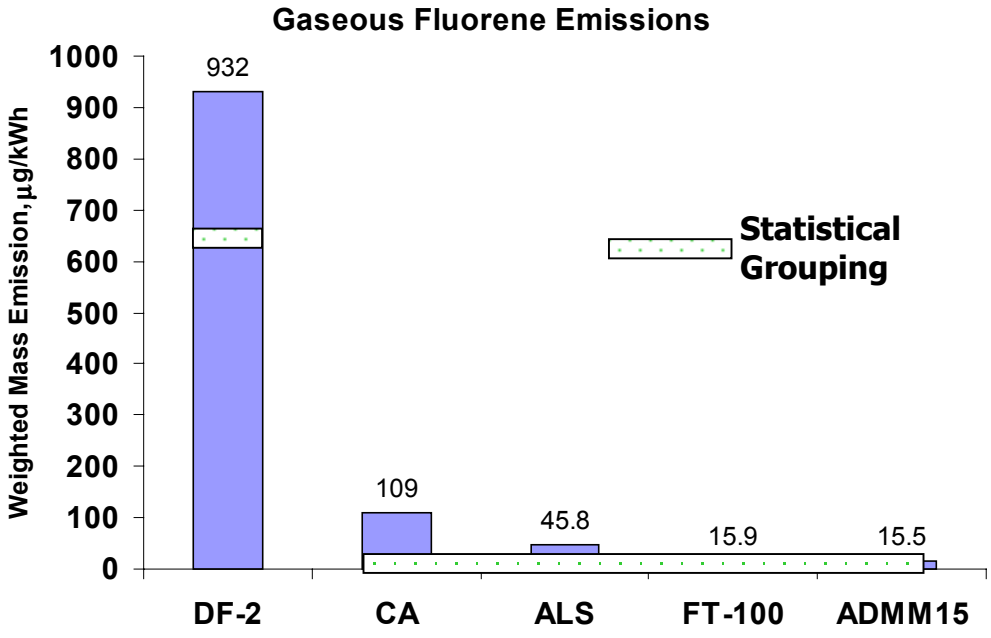


Figure 39. Test Fuel Weighted Average Gaseous Phase Fluorene Mass Emissions (µg/kWh)

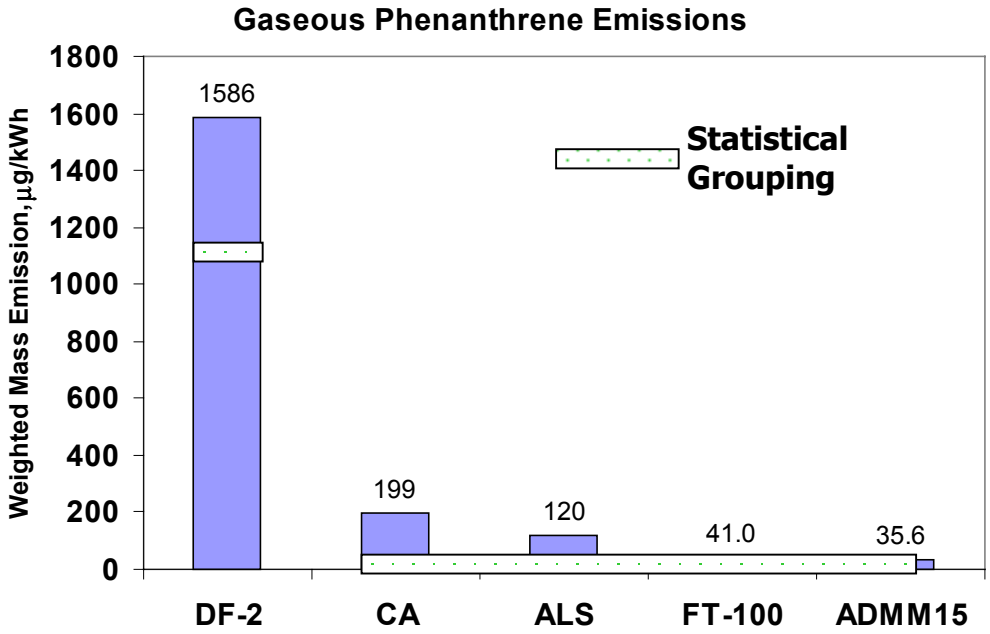


Figure 40. Test Fuel Weighted Average Gaseous Phase Phenanthrene Mass Emissions (µg/kWh)

5.4.9 Anthracene

The average weighted anthracene for the DF-2 fuel is significantly different than the other four fuels, Figure 41. The average weighted anthracene among the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another.

5.4.10 Fluoranthene

From Figure 42 the average weighted fluoranthene for the DF-2 fuel is seen to be significantly different than the other four fuels. The average weighted fluoranthene among the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

5.4.11 Pyrene

The average weighted pyrene for the DF-2 fuel is significantly different than the other four fuels. As seen in Figure 43, the average weighted pyrene for the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

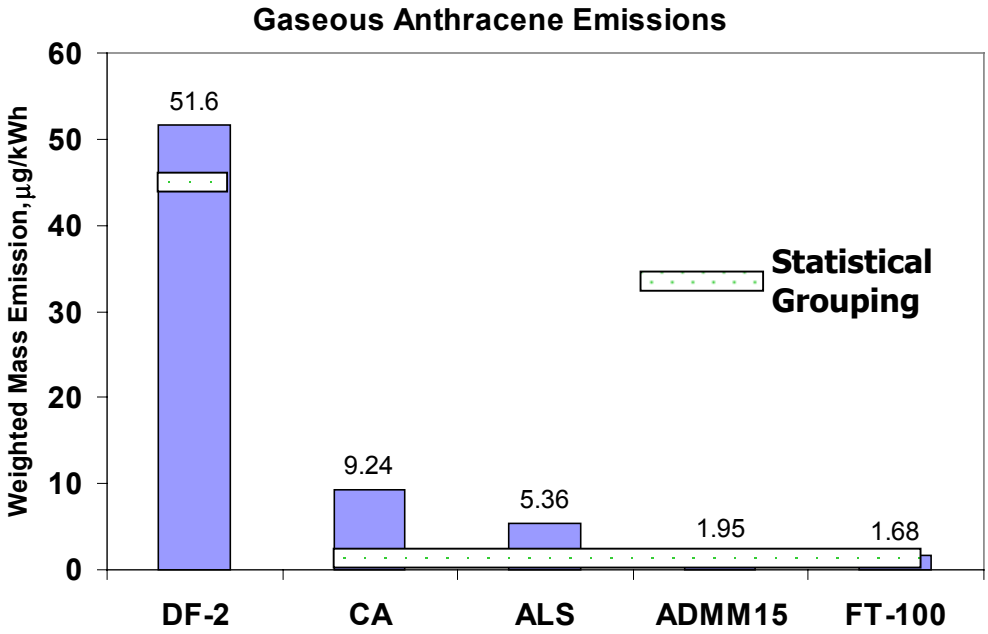


Figure 41. Test Fuel Weighted Average Gaseous Phase Anthracene Mass Emissions (µg/kWh)

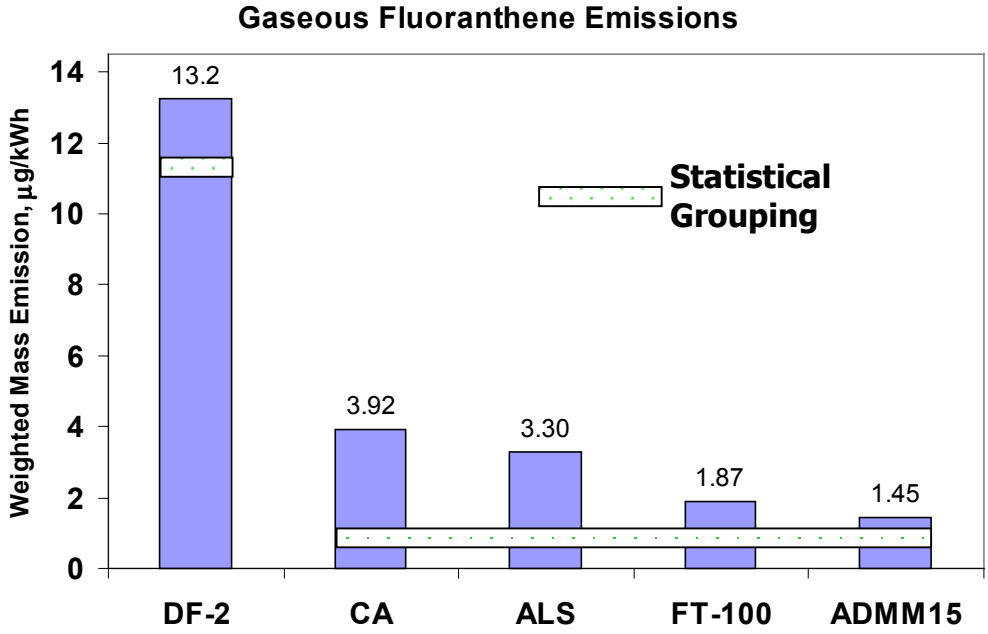


Figure 42. Test Fuel Weighted Average Gaseous Phase Fluoranthene Mass Emissions (µg/kWh)

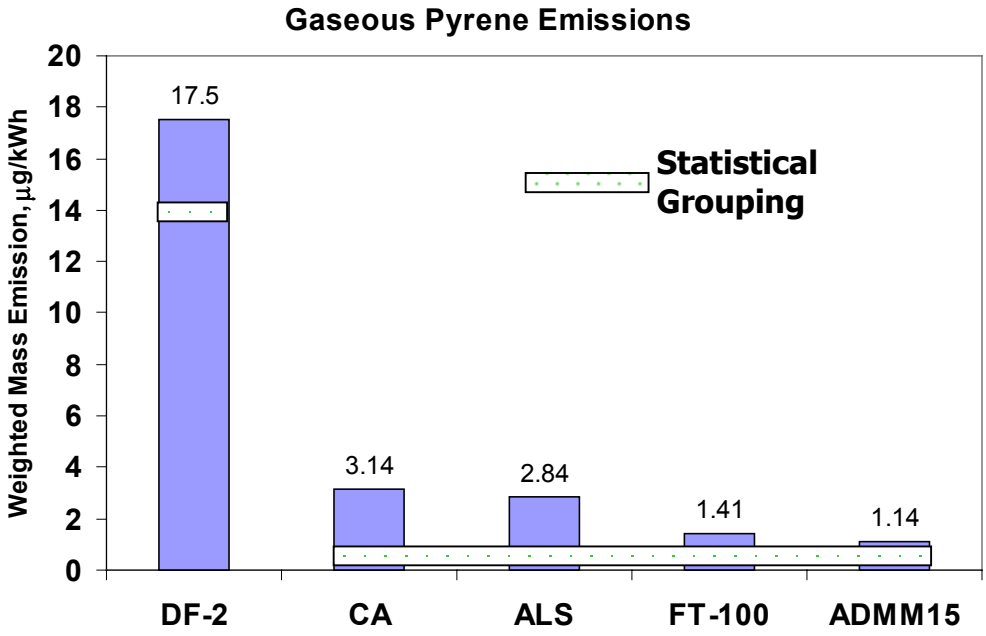


Figure 43. Test Fuel Weighted Average Gaseous Phase Pyrene Mass Emissions (µg/kWh)

6.0 FUEL IMPACT ON EMISSIONS-MODAL LPP TESTS

Fuel comparisons were made for the modal brake specific exhaust emissions with the engine operated under LPP control with the pilot fuel injection turned off. The multifactor ANOVA included fuel effects, mode effects, and fuel/mode interaction effects. The ANOVA tables for the modal LPP Operation (modes 5,6,10,11) can be found in Appendix E.

6.1 Fuel Impact on Regulated Brake Specific Mass Emissions

Several statistically significant trends, at 95% confidence, were apparent from an ANOVA of the modal brake specific emissions data. Table 20 summarizes the general rank order for the regulated modal mass emissions during LPP engine operation with pilot fuel injection turned off. The table displays the fuels rank from highest response to lowest response for the least-square means of the modal analysis. Statistically significant similar fuel groupings are also shown for each emission response in Table 20.

Table 20. Mass Emissions for Modal LPP Operation Mass Emissions ANOVA Summary for LPP Mode Analysis							
Response	Five Fuels, Modes 5, 6, 10 and 11						
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interaction
BSPM	DF-2	0.2774	A	10	0.2522	A	Fuel*Mode
	CA	0.2471	AB	6	0.2273	A	
	ALS	0.2177	B	11	0.1809	B	
	ADMM15	0.1454	C	5	0.1614	B	
	FT-100	0.1397	C				
$BSNO_X$	DF-2	5.901	A	5	9.658	A	Fuel*Mode
	ADMM15	5.696	A	6	5.560	B	
	FT-100	5.241	B	10	3.556	C	
	CA	5.057	B	11	2.780	D	
	ALS	5.047	B				
BSHC	DF-2	1.031	A	10	1.185	A	Fuel*Mode
	CA	0.8661	B	11	0.9348	B	
	ALS	0.5625	C	6	0.3463	C	
	ADMM15	0.5191	C	5	0.1589	D	
	FT-100	0.3026	D				
BSCO	DF-2	3.616	A	10	5.052	A	Fuel*Mode
	CA	3.467	A	11	3.656	B	
	ALS	2.273	B	6	1.229	C	
	ADMM15	2.218	B	5	0.4263	D	
	FT-100	1.381	C				
$BSCO_2$	ADMM15	884.1	A	10	1056	A	NS
	DF-2	874.4	A	11	894.1	B	
	CA	844.7	B	6	779.3	C	
	ALS	844.0	B	5	678.4	D	
	FT-100	812.4	C				
BSSOF	DF-2	0.2091	A	10	0.2147	A	Fuel*Mode
	CA	0.1906	A	11	0.1377	B	
	ALS	0.1510	B	6	0.1343	B	
	ADMM15	0.1251	B	5	0.1189	B	
	FT-100	0.0812	C				

[1]Factor levels listed from highest to lowest least squares mean

[2]Letters designate groups of factor means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

Table 20 includes the modal test severity for each regulated emission. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average mass emissions at each test mode. The general trend for mode severity depends on the species of interest. Fuel*Mode interactions are indicated in Table 20 for each toxic air pollutant.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the modal operation, and refer to the results in Table 20.

6.1.1 Fuel Impact on Particulate

Statistically significant differences were apparent in the average total particulates among the fuels, modes, and fuel*mode interaction. The average particulate at fuels FT-100 and ADMM15 are not significantly different from one another, but are different than the other 3 fuels. The average particulate at Fuel ALS is significantly different than Fuel DF-2. The CA fuel is not significantly different than either the ALS or DF-2 fuel.

The average particulate at Modes 5 and 11 are not significantly different from one another. Average particulate at Modes 6 and 10 are not significantly different from one another. Average particulate at modes 5 and 11 are significantly different than modes 6 and 10.

The CA and DF-2 fuels have significantly different average total particulate at Modes 5 and 11 than at modes 6 and 10. All other fuels do not demonstrate significant differences in the average total particulate among the four modes.

6.1.2 Fuel Impact on NOx

Statistically significant differences were apparent in the average $BSNO_X$ among the fuels, modes, and fuel*mode interaction. There are two distinct fuel groupings with respect to the average $BSNO_X$. ADMM15 and DF-2 fuels are not significantly different from one another, but are different from the average $BSNO_X$ for the ALS, CA, and FT-100 fuels. The ALS, CA, and FT-100 fuels are not significantly different from one another.

All four modes are significantly different from one another with respect to the average $BSNO_X$.

While the ADMM15, ALS, CA, and FT-100 fuels all have significant differences in the average $BSNO_X$ between mode 6 and modes 10 and 11, the DF-2 fuel does not demonstrate this difference. The average $BSNO_X$ among modes 6, 10, and 11 for the DF-2 are not significantly different from one another.

6.1.3 Fuel Impact on HC

Statistically significant differences were apparent in the average BSHC among the fuels, modes, and the fuel*mode interaction. There are four distinct fuel groupings with respect to the average BSHC. FT-100, CA, and DF-2 fuels are all significantly different from one another. Also, fuels ADMM15 and ALS are not significantly different from one another, but they are both significantly different from the other three fuels.

All four modes are significantly different from one another with respect to the average BSHC.

The ALS, CA, DF-2 fuels have significantly different average BSHC at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average BSHC among the four modes.

6.1.4 Fuel Impact on CO

Statistically significant differences were noted in the average BSCO among the fuels, modes, and fuel*mode interaction. There are three distinct fuel groupings with respect to the average BSCO. FT-100 is significantly different from the other four fuels. ADMM15 and ALS are not significantly different from one another. Fuels CA and DF-2 are not significantly different from one another, but are significantly different from the ADMM15 and ALS fuels.

All four modes are significantly different from one another with respect to the average BSCO.

The CA, DF-2, and FT-100 fuels have significantly different average BSCO at modes 10 and 11 than at modes 5 and 6.

6.1.5 Fuel Impact on CO_2

Statistically significant differences were apparent in the average $BSCO_2$ among the fuels and the modes. There are three distinct fuel groupings with respect to the average $BSCO_2$. FT-100 is significantly different from the other four fuels. ADMM15 and DF-2 fuels are not significantly different from one another. Fuels ALS and CA are not significantly different from one another, but are significantly different from the ADMM15 and DF-2 fuels.

All four modes are significantly different from one another with respect to the average $BSCO_2$.

No significant differences were observed among the fuel and mode combinations with respect to the average $BSCO_2$.

6.1.6 Fuel Impact on SOF of PM

Statistically significant differences were noted in the average BSSOF among the fuels, modes, and fuel*mode interaction. There are three distinct fuel groupings with respect to the average BSSOF. The FT-100 fuel is significantly different from the remaining four fuels. The DF-2 and CA fuels are not significantly different from one another, but are different from the other three fuels. Also, the ALS and ADMM15 fuels are not significantly different from one another, but are different from the other three fuels.

The average BSSOF for mode 10 is significantly different from the remaining three modes. The average BSSOF for modes 5, 6, and 11 are not significantly different from one another.

The trend in the average BSSOF across the fuels is different for mode 10 at the CA and DF-2 fuels. The trends in the average BSSOF across the fuels for modes 5, 6, and 11 do not appear to be different.

6.2 Fuel Impact on Four Clean Air Act Toxic Air Pollutants

Table 21 is the ranking of the test fuels from multifactor ANOVA for the four EPA Clean Air Act (CAA) toxic air pollutants. For the EPA toxic air pollutants, ADMM15 and FT-100 were statistically similar emitting fuels, and always in the lowest grouping for the modal average for LPP operation with pilot fuel injection turned off.

Table 21 includes the modal test severity for each CAA toxic air pollutant. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average mass emissions at each test mode. The general trends were for mode 10 and mode 11 to have the highest toxic emissions, while mode 5 and mode 6 had the statistically lowest toxic emissions. Fuel*Mode interactions are indicated in Table 21 for each toxic air pollutant.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the modal operation, and refer to the results in Table 21. The ANOVA tables for the modal LPP Operation (modes 5,6,10,11) can be found in Appendix E.

6.2.1 Benzene

Statistically significant differences were apparent in the average benzene among the fuels, modes, and fuel*mode interaction. The average benzene for the ADMM15 and FT-100 fuels are not significantly different from one another, but are significantly different from the remaining three fuels. The average benzene for the ALS fuel is significantly different than the average benzene for the CA fuel.

There are three distinct mode groupings with respect to the average benzene. Modes 10 and 11 are not significantly different from one another, but are significantly different than the other two modes. Modes 5 and 6 are significantly different from one another and the other two modes.

The ALS, CA, and DF-2 fuels have significantly different average benzene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average Benzene among the four modes.

6.2.2 1,3-Butadiene

Statistically significant differences exist in the average 1,3 butadiene among the fuels, modes, and fuel*mode interaction. There are three distinct fuel groupings with respect to the average 1,3-butadiene. The average 1,3-butadiene for the FT-100 fuel is significantly different than the remaining four fuels. The ADMM15 and ALS fuels are not significantly different from one another, but are significantly different than the other three fuels. Also, the DF-2 and CA fuels are not significantly different from one another, but are significantly different from the other three fuels.

Table 21. Clean Air Act Toxic Air Pollutant Mass Emissions (mg/k Wh) ANOVA Summary for LPP Mode Analysis							
Response	Five Fuels, Modes 5, 6, 10 and 11						
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interaction
Benzene	CA	5.0951	A	10	5.8422	A	Fuel*Mode
	DF-2	4.3477	AB	11	5.0279	A	
	ALS	3.4599	B	6	1.7100	B	
	FT-100	1.8114	C	5	0.3923	C	
	ADMM15	1.5014	C				
1,3-Butadiene	CA	4.2291	A	10	6.3958	A	Fuel*Mode
	DF-2	3.9996	A	11	4.8603	B	
	ALS	3.1861	B	6	1.0916	C	
	ADMM15	2.7986	B	5	0.5601	C	
	FT-100	1.9214	C				
Formaldehyde	DF-2	343.9870	A	10	476.8070	A	Fuel*Mode
	CA	271.7800	AB	11	339.8470	B	
	ALS	258.6100	B	6	107.7750	C	
	ADMM15	195.5480	BC	5	59.7879	C	
	FT-100	160.3470	C				
Acetaldehyde	DF-2	128.3360	A	10	175.9990	A	Fuel*Mode
	CA	105.5910	A	11	127.3040	B	
	ALS	104.8070	A	6	43.4665	C	
	ADMM15	69.0340	B	5	26.3907	C	
	FT-100	58.6822	B				
[1]Factor levels listed from highest to lowest least squares mean							
[2]Letters designate groups of factor means within which there are no statistically significant differences							
NS = no statistically significant differences in the mean response at the 5% level of significance							

There are three distinct mode groupings with respect to the average 1,3-butadiene. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another but are significantly different from the other two modes.

The DF-2 and CA fuels have significantly different average 1,3-butadiene at mode 10 than at the remaining three modes. All other fuels do not demonstrate significant differences in the average 1,3-butadiene among the four modes.

6.2.3 Formaldehyde

Statistically significant differences were noted in the average formaldehyde among the fuels, modes, and fuel*mode interaction. The average formaldehyde for the DF-2 fuel is not significantly different than the average formaldehyde for the CA fuel, but it is significantly different than the ADMM15, FT-100, and ALS fuels. The average formaldehyde at the FT-100 fuel is not significantly different than the ADMM15 fuel, but it is significantly different than the ALS, CA, and DF-2 fuels.

There are three distinct mode groupings with respect to the average formaldehyde. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another but are significantly different from the other two modes.

The ALS and DF-2 fuels have significantly different average formaldehyde at modes 10 and 11 than at the remaining two modes. All other fuels do not demonstrate this difference. However, the average formaldehyde for the CA fuel at mode 10 is significantly different than the other three modes.

6.2.4 Acetaldehyde

Statistically significant differences were apparent in the average acetaldehyde among the fuels, modes, and fuel*mode interaction. The average acetaldehyde for the FT-100 and ADMM15 fuels are not significantly different from one another. The average acetaldehyde for the ALS, CA, and

DF-2 fuels are not significantly different from one another, but are significantly different from the FT-100 and ADMM15 fuels.

There are three distinct mode groupings with respect to the average acetaldehyde. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another but are significantly different from the other two modes.

The ALS and DF-2 fuels have significantly different average acetaldehyde at modes 10 and 11 than at the remaining two modes. All other fuels do not demonstrate this difference. However, the average acetaldehyde for the CA fuel at mode 10 is significantly different than the other three modes.

6.3 Fuel Impact on Particulate Soluble Extract PAH Species

The fuel rankings for the particulate bound soluble phase PAH compounds are shown in Table 22. Due to non-detects, four PAH compounds were reanalyzed with a gas GC-high resolution mass spectrometer. The four compounds reanalyzed were benzo[a]pyrene, indeno(123-cd)pyrene, dibenzo(a,h)anthracene, and benzo(ghi)perylene. For the majority of PAH compounds DF-2 fuel was statistically different from the other test fuels. The ADMM15 and FT-100 fuels were in the statistically equivalent (95% confidence) lowest grouping for particulate bound PAH compounds.

The soluble extract PAH emissions rank the test modal severity as shown in Table 22. Included in Table 22 are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average mass emissions at each test mode. The general trends were for mode 10 to having the highest soluble extract PAH emissions, and mode 5 having the statistically lowest PAH emissions. Fuel*Mode interactions are indicated in Table 22 for each gaseous PAH species.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the modal operation. The ANOVA tables for the modal LPP Operation (modes 5,6,10,11) can be found in Appendix E.

Table 22. Soluble PAH Mass Emissions (µg/kWh) ANOVA Summary for LPP Mode Analysis							
Response	**Five Fuels, Modes 5, 6, 10 and 11**						
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**	**Mode**	**LS Means[1]**	**Significant Mode Groups[2]**	**Significant Interaction**
Naphthalene	CA	45.50	A	10	44.80	A	NS
	DF-2	43.35	A	6	38.08	AB	
	FT-100	36.76	AB	11	34.32	AB	
	ADMM15	28.41	B	5	27.65	B	
	ALS	27.04	B				
Acenaphthylene	CA	0.9153	A	10	0.7630	NS	NS
	DF-2	0.7622	AB	6	0.6689		
	ALS	0.5971	AB	11	0.6559		
	FT-100	0.5449	B	5	0.5493		
	ADMM15	0.4768	B				
Acenaphthene	DF-2	6.393	NS	10	5.638	NS	NS
	CA	5.239		6	5.128		
	ADMM15	4.343		11	4.441		
	FT-100	4.144		5	3.801		
	ALS	3.643					
Fluorene	DF-2	11.35	A	10	9.249	NS	NS
	CA	9.128	AB	11	8.197		
	ALS	7.275	AB	6	7.834		
	ADMM15	7.043	AB	5	7.172		
	FT-100	5.769	B				
Phenanthrene	DF-2	88.83	A	6	64.4332	A	NS
	CA	74.61	A	10	61.7122	A	
	ALS	38.36	B	11	54.5710	AB	
	FT-100	38.16	B	5	34.0794	B	
	ADMM15	28.54	B				
Anthracene	CA	4.246	A	10	3.3277	A	NS
	DF-2	3.629	AB	6	3.1338	AB	
	FT-100	2.661	B	11	2.7156	AB	
	ADMM15	2.299	BC	5	2.0872	B	
	ALS	1.246	C				

Table 22. Soluble PAH Mass Emissions (µg/kWh) ANOVA Summary for LPP Mode Analysis (contd)							
Response	Five Fuels, Modes 5, 6, 10 and 11						
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interaction
Fluoranthene	DF-2	40.77	A	10	25.8812	A	Fuel*Mode
	CA	20.35	B	6	24.5815	A	
	ALS	19.29	B	11	20.6494	AB	
	FT-100	14.82	B	5	12.6339	B	
	ADMM15	9.455	B				
Pyrene	DF-2	63.29	A	10	31.1162	A	Fuel*Mode
	ALS	19.18	B	11	28.2235	A	
	CA	16.05	B	6	24.5073	AB	
	FT-100	11.87	B	5	11.6778	B	
	ADMM15	9.020	B				
Benzo[a]anthracene	DF-2	1.995	A	10	1.1663	A	Fuel*Mode
	CA	1.163	B	11	0.8571	AB	
	ALS	0.7054	C	6	0.7489	B	
	FT-100	0.2040	D	5	0.6127	B	
	ADMM15	0.1636	D				
Chrysene	DF-2	6.774	A	10	3.2797	NS	NS
	CA	2.425	B	6	2.5967		
	ALS	2.250	BC	11	2.4567		
	FT-100	0.8623	BC	5	2.1010		
	ADMM15	0.7316	C				
Benzo[b]fluoranthene	CA	1.715	A	5	1.3636	NS	NS
	ALS	1.496	A	10	1.1534		
	DF-2	1.377	A	6	1.0215		
	ADMM15	0.4814	B	11	0.7956		
	FT-100	0.3485	B				
Benzo[k]fluoranthene	DF-2	2.226	A	10	1.4836	A	NS
	CA	1.394	AB	5	1.1171	AB	
	ALS	0.7976	BC	6	1.0296	AB	
	ADMM15	0.5213	BC	11	0.6652	B	
	FT-100	0.4298	C				

Table 22. Soluble PAH Mass Emissions (µg/kWh) ANOVA Summary for LPP Mode Analysis (contd)							
Response	**Five Fuels, Modes 5, 6, 10 and 11**						
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**	**Mode**	**LS Means[1]**	**Significant Mode Groups[2]**	**Significant Interaction**
Benzo[e]pyrene	CA	1.106	A	10	0.7553	NS	NS
	DF-2	0.9574	A	5	0.6853		
	ALS	0.5997	AB	6	0.6049		
	FT-100	0.2621	B	11	0.4718		
	ADMM15	0.2215	B				
Benzo[a]pyrene	ALS	0.3761	A	10	0.3038	A	Fuel*Mode
	CA	0.3388	A	11	0.1864	B	
	DF-2	0.1713	B	6	0.1703	B	
	FT-100	0.0598	BC	5	0.1404	B	
	ADMM15	0.0550	C				
Indeno(1,2,3-cd)pyrene	DF-2	0.3111	A	10	0.2457	A	Fuel*Mode
	ADMM15	0.0651	B	11	0.1649	AB	
	FT-100	0.0624	B	6	0.0947	B	
				5	0.0794	B	
Dibenzo[a,h]anthracene	DF-2	0.0818	A	10	0.0546	A	NS
	FT-100	0.0156	B	11	0.0413	AB	
	ADMM15	0.0122	B	6	0.0302	AB	
				5	0.0200	B	
Benzo[ghi]perylene	CA	0.5739	A	10	0.5886	A	Fuel*Mode
	DF-2	0.4977	A	11	0.4190	B	
	ADMM15	0.1747	B	6	0.2063	C	
	FT-100	0.1475	B	5	0.1799	C	

[1]Factor levels listed from highest to lowest least squares mean

[2]Letters designate groups of factor means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

6.3.1 Naphthalene

Statistically significant differences were apparent in the average naphthalene among the fuels and the modes. The average naphthalene for the CA and DF-2 fuels are significantly different from the ADMM15 and ALS fuels, but not significantly different from one another. The average naphthalene for the ADMM15 and ALS fuels are not significantly different from one another.

The average naphthalene for mode 10 is significantly different from mode 5.

There is no significant interaction in the average naphthalene among the fuel and mode combinations.

6.3.2 Acenaphthylene

Statistically significant differences exist in the average acenaphthylene among the fuels. The average acenaphthylene for the CA fuel is significantly different than the FT-100 and ADMM15 fuels.

No statistically significant differences exist in the average acenaphthylene among the modes.

There is no significant interaction in the average acenaphthylene among the fuel and mode combinations.

6.3.3 Acenaphthene

No statistically significant differences were apparent in the average acenaphthene among the fuels, modes or interaction. No statistically significant differences exist in the average acenaphthene among the fuels.

No statistically significant differences were apparent in the average acenaphthene among the modes.

There is no significant interaction in the average acenaphthene among the fuel and mode combinations.

6.3.4 Fluorene

Statistically significant differences were noted in the average fluorene among the fuels. The average fluorene for the DF-2 fuel is significantly different from the FT-100 fuel.

There is no significant difference in the average fluorene among the modes.

There is no significant interaction in the average fluorene among the fuel and mode combinations.

6.3.5 Phenanthrene

Statistically significant differences were apparent in the average phenanthrene among the fuels and modes. There are two distinct fuel groupings with respect to the average phenanthrene. The average phenanthrene for the DF-2 and CA fuels are not significantly different from one another, but are significantly different from the remaining three fuels. The average phenanthrene for the ALS, FT-100, and ADMM15 fuels are not significantly different from one another.

The average phenanthrene for mode 5 is significantly different from modes 6 and 10.

There is no significant interaction in the average phenanthrene among the fuel and mode combinations.

6.3.6 Anthracene

Statistically significant differences were apparent in the average anthracene among the fuels and modes. The average anthracene for the CA fuel is significantly different from the FT-100, ADMM15, and ALS fuels. The average anthracene for the ALS fuel is significantly different than the DF-2 and FT-100 fuels.

The average anthracene for mode 10 is significantly different than mode 5.

There is no significant interaction in the average anthracene among the fuel and mode combinations.

6.3.7 Fluoranthene

Statistically significant differences exist in the average fluoranthene among the fuels, modes and fuel*mode interaction. The average fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

The average fluoranthene for modes 6 and 10 are significantly different than mode 5, but not significantly different from one another.

The trend in the average fluoranthene across the modes for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average fluoranthene for the DF-2 fuel at modes 10 and 11 are significantly different than the other four fuels.

6.3.8 Pyrene

Statistically significant differences were noted in the average pyrene among the fuels, modes, and fuel*mode interaction. The average pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The average pyrene for the ALS, CA, FT-100, and ADMM15 fuels are not significantly different from one another.

The average pyrene for modes 10 and 11 are significantly different than mode 5. The average pyrene for mode 6 is not significantly different than the remaining three modes.

The trend in the average pyrene across the modes for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average pyrene at modes 10 and 11 for the DF-2 fuel are significantly different than the other four fuels.

6.3.9 Benzo[a]anthracene

Statistically significant differences were apparent in the average benzo[a]anthracene among the fuels, modes, and fuel*mode interaction. There are four distinct fuel groupings with respect to the average benzo[a]anthracene. Fuels DF-2, CA, and ALS are significantly different from one another and the remaining two fuels. The FT-100 and ADMM15 fuels are not significantly

different from one another, but are significantly different than the other three fuels.

The average benzo[a]anthracene for mode 10 is significantly different than modes 5 and 6. The average benzo[a]anthracene for mode 11 is not significantly different than the remaining three modes.

The trend in the average benzo[a]anthracene across the modes for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average benzo[a]anthracene at modes 10 and 11 for the DF-2 fuel are significantly different than the other four fuels.

6.3.10 Chrysene

Statistically significant differences exist in the average chrysene among the fuels. The average chrysene for the DF-2 fuel is significantly different than the remaining four fuels. Also, the average chrysene for the CA fuel is significantly different than the ADMM15 fuel.

There is no significant difference in the average chrysene among the modes.

There is no significant interaction in the average chrysene among the fuel and mode combinations.

6.3.11 Benzo[b]fluoranthene

Statistically significant differences were apparent in the average benzo[b]fluoranthene among the fuels. There are two distinct fuel groupings with respect to the average benzo[b]fluoranthene. The CA, ALS, and DF-2 fuels are not significantly different from one another, but are different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another.

There is not any significant difference in the average benzo[b]fluoranthene among the modes.

There is not any significant interaction in the average benzo[b]fluoranthene among the fuel and mode combinations.

6.3.12 Benzo[k]fluoranthene

Statistically significant differences were noted in the average benzo[k]fluoranthene among the fuels and modes. The average benzo[k]fluoranthene for the DF-2 fuel is significantly different than the ADMM15, ALS, and FT-100 fuels. The average benzo[k]fluoranthene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another. Also, the average benzo[k]fluoranthene for the CA fuel is significantly different than the FT-100 fuel.

The average benzo[k]fluoranthene for mode 10 is significantly different than mode 11.

There is no significant interaction in the average benzo[k]fluoranthene among the fuel and mode combinations.

6.3.13 Benzo[e]pyrene

Statistically significant differences were apparent in the average benzo[e]pyrene among the fuels. The average benzo[e]pyrene for the CA and DF-2 fuels are significantly different than the FT-100 and ADMM15 fuels, but not significantly different from one another. Also, the average benzo[e]pyrene for the ALS fuel was not significantly different from the remaining four fuels.

There is no significant difference in the average benzo[e]pyrene among the modes.

There is no significant interaction in the average benzo[e]pyrene among the fuel and mode combinations.

6.3.14 Benzo[a]pyrene

Due to non-detects for benzo[a]pyrene using low-resolution GC/MS, the extracts were reanalyzed utilizing a high-resolution mass spectrometer. The selection criteria for reanalysis was any non-idle modal experiment that did not have a benzo[a]pyrene result. The ALS fuel had benzo[a]pyrene detects with the low resolution instrument, so the majority of the ALS extracts were not reanalyzed for the higher molecular weight PAH species.

Statistically significant differences exist in the average benzo[a]pyrene among the fuels, modes, and fuel*mode interaction. The average benzo[a]pyrene for the CA and ALS fuels are significantly different from the remaining three fuels but not different from one another. The average benzo[a]pyrene for the ADMM15 fuel is significantly different from the DF-2 fuel, but not significantly different from the FT-100 fuel.

The average benzo[a]pyrene for mode 10 is significantly different from the remaining three modes.

The trend in the average benzo[a]pyrene across the modes for the ALS fuel is significantly different than the trends for the remaining four fuels. Also, the average benzo[a]pyrene for the CA fuel is significantly different than the other fuels at mode 6.

6.3.15 Indeno(1,2,3-cd)pyrene

High-resolution mass spectral analysis of the extracts were also performed for the PAH indeno(1,2,3-cd)pyrene. Sufficient non-detects existed for CA and ALS fuels such that the CA and ALS fuels were not included in the multifactor ANOVA for indeno(1,2,3-cd)pyrene.

Statistically significant differences were apparent in the average indeno(1,2,3-cd)pyrene among the fuels, modes, and fuel*mode interaction. The average indeno(1,2,3-cd)pyrene for the DF-2 fuel is significantly different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another with respect to the average indeno(1,2,3-cd)pyrene.

The average indeno(1,2,3-cd)pyrene for mode 10 is significantly different than modes 5 and 6. Mode 11 is not significantly different from the remaining three modes with respect to the average indeno(1,2,3-cd)pyrene.

The trend in the average indeno(1,2,3-cd)pyrene across the modes for the DF-2 fuel is significantly different than the trends in the remaining two fuels. The average indeno(1,2,3-cd)pyrene at modes 10 and 11 for the DF-2 fuel are significantly different than the ADMM15 and FT-100 fuels.

6.3.16 Dibenzo[a,h]anthracene

Although high-resolution mass spectral analysis was attempted on this PAH species, sufficient non-detects existed for CA and ALS fuels such that the multifactor ANOVA for dibenzo[a,h]anthracene was not be performed for the CA and ALS fuels.

Statistically significant differences were noted in the average dibenzo[a,h]anthracene among the fuels and modes analyzed. The average dibenzo[a,h]anthracene for the DF-2 fuel is significantly different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another.

The average dibenzo[a,h]anthracene for mode 10 is significantly different from mode 5. Modes 6 and 11 are not significantly different from one another or the other two modes.

There is no significant interaction in the average dibenzo[a,h]anthracene among the fuel and mode combinations.

6.3.17 Benzo[ghi]perylene

High-resolution mass spectral analysis of the extracts were also performed for the PAH benzo[ghi]perylene except for several ALS fuel runs. Because sufficient non-detects existed for the ALS fuels, that ALS was not included in the multifactor ANOVA for benzo[ghi]perylene.

Statistically significant differences were apparent in the average benzo[ghi]perylene among the fuels, modes and fuel*mode interaction. There are two distinct fuel groupings with respect to the average benzo[ghi]perylene. The CA and DF-2 fuels are not significantly different from one another, but are different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another.

There are three distinct mode groupings with respect to the average benzo[ghi]perylene. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another, but are significantly different than the other two modes.

The trend in the average benzo[ghi]perylene across the modes for the DF-2 and CA fuels is significantly different than the trends in the remaining two fuels. The average benzo[ghi]perylene at modes 10 and 11 for the DF-2 and CA fuels are significantly different than the ADMM15 and FT-100 fuels.

6.4 Fuel Impact on Gaseous PAH Species

The gas phase PAH emissions rank the test fuels in the general order shown in Table 23. Included in Table 23 are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the modal average mass emissions. The general trends were for DF-2 to have the highest gas phase PAH emissions, while ADMM15 and FT-100 always had the statistically lowest PAH emissions. The ANOVA for gas phase PAH species indicated the oxygenated diesel fuel, ADMM15, was statistically equivalent to FT-100.

The gas phase PAH emissions rank the test modal severity as shown in Table 23. Included in Table 23 are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average mass emissions at each test mode. The general trends were for mode 10 and mode 11 to have the highest gas phase PAH emissions, while mode 5 and mode 6 had the statistically lowest PAH emissions. Fuel*Mode interactions are indicated in Table 23 for each gaseous PAH species.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the modal operation. The ANOVA tables for the modal LPP Operation (modes 5,6,10,11) can be found in Appendix D.

6.4.1 Naphthalene

Statistically significant differences were noted in the average naphthalene among the fuels, modes, and fuel*mode interaction. There are four distinct fuel groupings with respect to the average naphthalene. ALS, DF-2, and CA fuels are all significantly different from one another. Also, fuels ADMM15 and FT-100 are not significantly different from one another, but they are both significantly different from the other three fuels.

Table 23. Gaseous Phase PAH Mass Emissions (µ/kWh) ANOVA Summary for LPP Mode Analysis							
Response	**Five Fuels, Modes 5, 6, 10 and 11**						
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**	**Mode**	**LS Means[1]**	**Significant Mode Groups[2]**	**Significant Interaction**
Naphthalene	CA	3881	A	10	2727	A	Fuel*Mode
	DF-2	2259	B	11	2191	B	
	ALS	950.0	C	6	883.5	C	
	ADMM15	352.7	D	5	323.1	D	
	FT-100	211.8	D				
2-Methylnaphthalene	DF-2	3291	A	10	2196	A	Fuel*Mode
	CA	2174	B	11	1949	A	
	ALS	646.6	C	6	694.0	B	
	ADMM15	183.3	C	5	282.9	B	
	FT-100	107.0	C				
1-Methylnaphthalene	DF-2	2257	A	10	1365	A	Fuel*Mode
	CA	1213	B	11	1229	A	
	ALS	363.9	C	6	421.1	B	
	ADMM15	86.50	C	5	170.7	B	
	FT-100	61.54	C				
2,6-Dimethylnaphthalene	DF-2	2402	A	10	1051	A	Fuel*Mode
	CA	522.1	B	11	1030	A	
	ALS	227.6	B	6	355.7	B	
	FT-100	43.52	B	5	152.3	B	
	ADMM15	41.35	B				
Acenaphthylene	DF-2	225.3	A	11	139.5	A	Fuel*Mode
	ALS	104.5	B	10	138.5	A	
	CA	82.82	B	6	82.40	AB	
	FT-100	40.01	B	5	30.83	B	
	ADMM15	36.39	B				
Acenaphthene	DF-2	358.3	A	11	158.7	A	Fuel*Mode
	CA	54.66	B	10	137.6	AB	
	ALS	32.11	B	6	54.50	BC	
	ADMM15	15.50	B	5	24.22	C	
	FT-100	8.100	B				

Table 23. Gaseous Phase PAH Mass Emissions (µ/kWh) ANOVA Summary for LPP Mode Analysis (contd)							
	Five Fuels, Modes 5, 6, 10 and 11						
Fluorene	DF-2	683.7	A	11	263.9	A	Fuel*Mode
	CA	83.73	B	10	220.7	AB	
	ALS	42.39	B	6	130.2	AB	
	FT-100	15.23	B	5	56.42	B	
	ADMM15	13.96	B				
Phenanthrene	DF-2	1343	A	10	424.0	NS	NS
	CA	179.9	B	11	412.7		
	ALS	139.7	B	6	342.6		
	FT-100	42.22	B	5	211.5		
	ADMM15	33.45	B				
Anthracene	DF-2	42.19	A	10	15.20	A	Fuel*Mode
	CA	8.300	B	11	14.41	AB	
	ALS	5.542	B	6	11.31	AB	
	ADMM15	1.770	B	5	6.635	B	
	FT-100	1.646	B				
Fluoranthene	DF-2	12.91	A	6	5.462	NS	NS
	CA	4.173	B	10	5.320		
	ALS	3.420	B	5	4.240		
	FT-100	1.972	B	11	4.201		
	ADMM15	1.550	B				
Pyrene	DF-2	16.84	A	6	5.853	NS	NS
	CA	3.323	B	10	5.518		
	ALS	3.008	B	11	4.894		
	FT-100	1.462	B	5	4.380		
	ADMM15	1.173	B				
[1]Factor levels listed from highest to lowest least squares mean							
[2]Letters designate groups of factor means within which there are no statistically significant differences							
NS = no statistically significant differences in the mean response at the 5% level of significance							

All four modes are significantly different from one another with respect to the average naphthalene.

The CA and DF-2 fuels have significantly different average naphthalene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average naphthalene among the four modes.

6.4.2 2-Methylnaphthalene

Statistically significant differences were apparent in the average 2-methylnaphthalene among the fuels, modes, and fuel*mode interaction. Average 2-methylnaphthalene at Modes 5 and 6 are not significantly different from one another, but significantly different from modes 10 and 11. Modes 10 and 11 are not significantly different from one another with respect to the average 2-methylnaphthalene.

Average 2-methylnaphthalene for fuels FT-100, ADMM15, and ALS are not significantly different from one another. The average 2-methylnaphthalene for fuels CA and DF-2 are significantly different from one another.

Modes 10 and 11 have significantly different average 2-methylnaphthalene for the CA and DF-2 fuels. All other fuels do not demonstrate differences in the average 2-methylnaphthalene among the four modes.

6.4.3 1-Methylnaphthalene

Statistically significant differences exist in the average 1-methylnaphthalene among the fuels, modes and fuel*mode interaction. There were three distinct fuel groupings with respect to the average 1-methylnaphthalene. CA and DF-2 fuels were significantly different from one another and the other three fuels. ADMM15, ALS, and FT-100 fuels were not significantly different from one another.

Average 1-methylnaphthalene at modes 5 and 6 are not significantly different from one another. Average 1-methylnaphthalene at modes 10 and 11 are not significantly different from one another, but are significantly different from modes 5 and 6.

The CA and DF-2 fuels have significantly different average 1-methylnaphthalene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average 1-methylnaphthalene among the four modes.

6.4.4 2,6-Dimethylnaphthalene

Statistically significant differences were noted in the average 2,6-Dimethylnaphthalene among the fuels, modes, and fuel*mode interaction. The average 2,6-dimethylnaphthalene for the DF-2 fuel is significantly different than the other four fuels. The average 2,6-dimethylnaphthalene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Average 2,6-dimethylnaphthalene at modes 5 and 6 are not significantly different from one another. Average 2,6-dimethylnaphthalene at modes 10 and 11 are not significantly different from one another, but are significantly different than modes 5 and 6.

The DF-2 fuel has significantly different average 2,6-dimethylnaphthalene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average 2,6-dimethylnaphthalene among the four modes.

6.4.5 Acenaphthylene

Statistically significant differences were apparent in the average acenaphthylene among the fuels, modes, and fuel*mode interaction. Average acenaphthylene is significantly different at fuel DF-2 compared to the other four fuels. Average acenaphthylene at fuels ADMM15, ALS, CA, and FT-100 are not significantly different from one another.

Average acenaphthylene at Mode 5 is significantly different from modes 10 and 11.

Modes 10 and 11 have significantly different average acenaphthylene for the DF-2 fuel. All other fuels do not demonstrate differences in the average acenaphthylene among the four modes.

6.4.6 Acenaphthene

Statistically significant differences exist in the average acenaphthene among the fuels, modes, and fuel*mode interaction. The average acenaphthene for the DF-2 fuel is significantly different than the average acenaphthene for the remaining four fuels.

The average acenaphthene for mode 5 is significantly different than the average acenaphthene for modes 10 and 11. The average acenaphthene for mode 6 is significantly different than the average acenaphthene for mode 11.

The average acenaphthene for the DF-2 fuel at modes 10 and 11 is significantly different than the average acenaphthene for modes 5 and 6. All the other fuels do not demonstrate differences in the average acenaphthene among the four modes.

6.4.7 Fluorene

Statistically significant differences were apparent in the average fluorene among the fuels, modes, and fuel*mode interaction. The average fluorene for the DF-2 fuel is significantly different than the average fluorene for the remaining four fuels.

The average fluorene for mode 5 is significantly different than the average fluorene for mode 11.

The average fluorene for the DF-2 fuel at modes 10 and 11 are significantly different than the average fluorene at mode 5. All the other fuels do not demonstrate differences in the average fluorene among the four modes.

6.4.8 Phenanthrene

Statistically significant differences were noted in the average phenanthrene among the fuels. The average phenanthrene for the DF-2 fuel is significantly different than the other four fuels. The average phenanthrene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

No significant differences exist in the average phenanthrene among the four modes.

No significant differences were observed among the fuel and mode combinations with respect to the average phenanthrene.

6.4.9 Anthracene

Statistically significant differences were apparent in the average anthracene among the fuels, modes, and fuel*mode interaction. The average anthracene for the DF-2 fuel is significantly different than the other four fuels. The average anthracene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

The average anthracene for mode 5 is significantly different than the average anthracene for mode 10.

The average anthracene for the DF-2 fuel at modes 6, 10, and 11 are significantly different than the anthracene for the other four fuels.

6.4.10 Fluoranthene

Statistically significant differences exist in the average fluoranthene among the fuels. The average fluoranthene for the DF-2 fuel is significantly different than the average fluoranthene for the remaining four fuels.

There is no significant difference in the average fluoranthene among the four modes.

There is no significant difference among the fuel and mode combinations with respect to the average fluoranthene.

6.4.11 Pyrene

Statistically significant differences were apparent in the average pyrene among the fuels. The average pyrene for the DF-2 fuel is significantly different than the average pyrene for the remaining four fuels.

There is no significant difference in the average pyrene among the modes.

There is no significant difference among the fuel and mode combinations with respect to the average pyrene.

7.0 FUEL IMPACT ON EMISSIONS-PILOT FUEL INJECTION STUDY

Fuel comparisons were made for the brake specific exhaust emissions with the engine operated utilizing three different control strategies. The control strategies were LPP(7°ATDC) control with the pilot fuel injection turned off, LPP control with the pilot fuel injection turned on (PilotA), and the OEM calibration strategy (PilotB). The multifactor ANOVA included fuel effects, pilot condition effects, mode effects, Fuel*Mode interaction effects, Fuel*Pilot interaction effects, Pilot*Mode interaction effects, and Fuel*Mode*Pilot interaction effects. The ANOVA tables for the pilot fuel injection evaluation can be found in Appendix F.

7.1 Fuel Impact on Regulated Brake Specific Mass Emissions

Several statistically significant trends, at 95% confidence, were apparent from an ANOVA of the pilot fuel injection condition emissions data. Table 24 summarizes the general rank order of the fuels for the regulated mass emissions across the three pilot control conditions and two modes. The table displays the fuels rank from highest response to lowest response for the Least-Square means of the pilot condition and modal analysis. Statistically significant similar fuel groupings are also shown for each emission response in Table 24.

Table 24 includes the pilot condition severity across fuels and modes for each regulated emission. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average mass emissions at each pilot condition. The general trend for pilot condition severity depends on the species of interest.

The mode severities across fuels and pilot condition for each regulated emission are also in Table 24. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average mass emissions at each mode. The general trend is mode 10 has significantly higher emissions than mode 11 across the fuels and pilot conditions. The Fuel*Mode, Fuel*Pilot, Pilot*Mode, and Fuel*Pilot*Mode interactions are indicated in Table 24 for each emission.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the pilot fuel injection study, and refer to the results in Table 24.

Table 24. Mass Emissions (g/kWh) ANOVA Summary for Pilot Fuel Injection Study										
Response	Five Fuels, Three Pilot Conditions, Modes 10 and 11									
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Pilot Condition	LS Means[1]	Significant Pilot Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interactions
BSPM	DF-2	0.4513	A	Pilot B	0.3876	A	10	0.3126	A	Pilot*Fuel Pilot*Mode
	CA	0.3424	B	Pilot A	0.2778	B	11	0.2754	B	
	ALS	0.2825	C	LPP	0.2166	C				
	FT-100	0.2094	D							
	ADMM15	0.1843	D							
BSNOX	DF-2	2.829	A	LPP	3.168	A	10	2.720	A	Pilot*Fuel Pilot*Mode Fuel*Mode
	CA	2.454	B	Pilot A	3.067	B	11	2.177	B	
	ADMM15	2.380	BC	Pilot B	1.112	C				
	ALS	2.322	C							
	FT-100	2.259	C							
BSHC	DF-2	2.110	A	Pilot A	1.395	A	10	1.487	A	Pilot*Fuel Pilot*Mode Fuel*Mode
	CA	1.691	B	Pilot B	1.327	A	11	1.035	B	
	ADMM15	0.9714	C	LPP	1.060	B				
	ALS	0.9651	C							
	FT-100	0.5656	D							
BSCO	DF-2	6.807	A	Pilot A	6.081	A	10	6.838	A	Pilot*Fuel Pilot*Mode Fuel*Mode Pilot*Fuel*Mode
	CA	6.302	B	Pilot B	5.313	B	11	3.661	B	
	ADMM15	5.436	C	LPP	4.354	C				
	ALS	4.506	D							
	FT-100	3.196	E							
BSCO2	ADMM15	1025	A	Pilot B	989.1	A	10	1064	A	Pilot*Fuel*Mode
	DF-2	1003	B	Pilot A	982.2	AB	11	900.6	B	
	CA	988.3	B	LPP	975.0	B				
	ALS	959.4	C							
	FT-100	935.1	D							
BSSOF	DF-2	0.3333	A	Pilot A	0.1844	A	10	0.1973	A	Pilot*Fuel Pilot*Mode Fuel*Mode Pilot*Fuel*Mode
	CA	0.1917	B	LPP	0.1762	AB	11	0.1503	B	
	ADMM15	0.1337	C	Pilot B	0.1609	B				
	ALS	0.1327	C							
	FT-100	0.0777	D							

[1]Factor levels listed from highest to lowest least squares mean

[2]Letters designate groups of factor means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

7.1.1 Fuel Impact on Total Particulate

Statistically significant differences exist for the average total particulate among the fuels, modes, pilot conditions, and some of the two-way interactions. The average total particulate for the ALS, CA, and DF-2 fuels are significantly different from each other and the remaining two fuels as seen in Figure 44. The average total particulate for the ADMM15 and FT-100 fuels are not significantly different from one another.

The average total particulate at all three pilot conditions are significantly different from each other. Statistical groupings for engine control strategy, which includes pilot fuel injection effects, from the ANOVA for fuels and modes, are shown in Figure 45 for total particulate.

Modes 10 and 11 are significantly different from one another with respect to average total particulate.

The trend in the average total particulate across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average total particulate for the DF-2 at the Pilot B condition is significantly different than the other four fuels; however, there is not a significant difference at the LPP condition.

There is a significant interaction among the mode and pilot condition combinations. While the average total particulate at mode 11 is significantly different at the LPP and Pilot A conditions, there is not any significant difference at the Pilot B condition.

There is no significant interaction in the average total particulate among the fuel and mode combinations.

7.1.2 Fuel Impact on NO_X

Statistically significant differences exist for the average NO_X among the fuels, modes, pilot conditions, and two-way interactions. The average NO_X for the DF-2 fuel is significantly different than the remaining four fuels. The CA fuel has significantly different average NO_X than the ALS and FT-100 fuels. Also, the FT-100, CA, and ADMM15 fuels are not significantly different from one another. The fuels rankings across pilot conditions are shown in Figure 46.

All three pilot conditions are significantly different from one another with respect to the average NO_X. Statistical groupings for engine control strategy, which includes pilot fuel injection effects, from the ANOVA for fuels and modes, are shown in Figure 47 for NO_X.

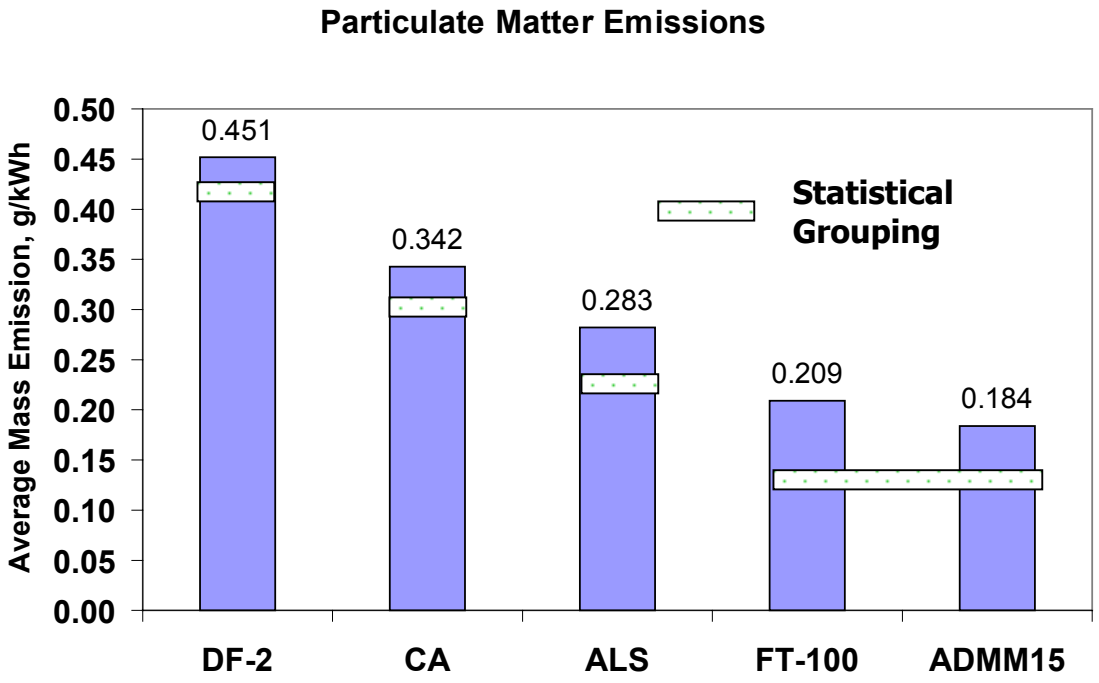


Figure 44. Test Fuel Average Total Particulate Mass Emissions for Pilot Conditions and Modes (g/kWh)

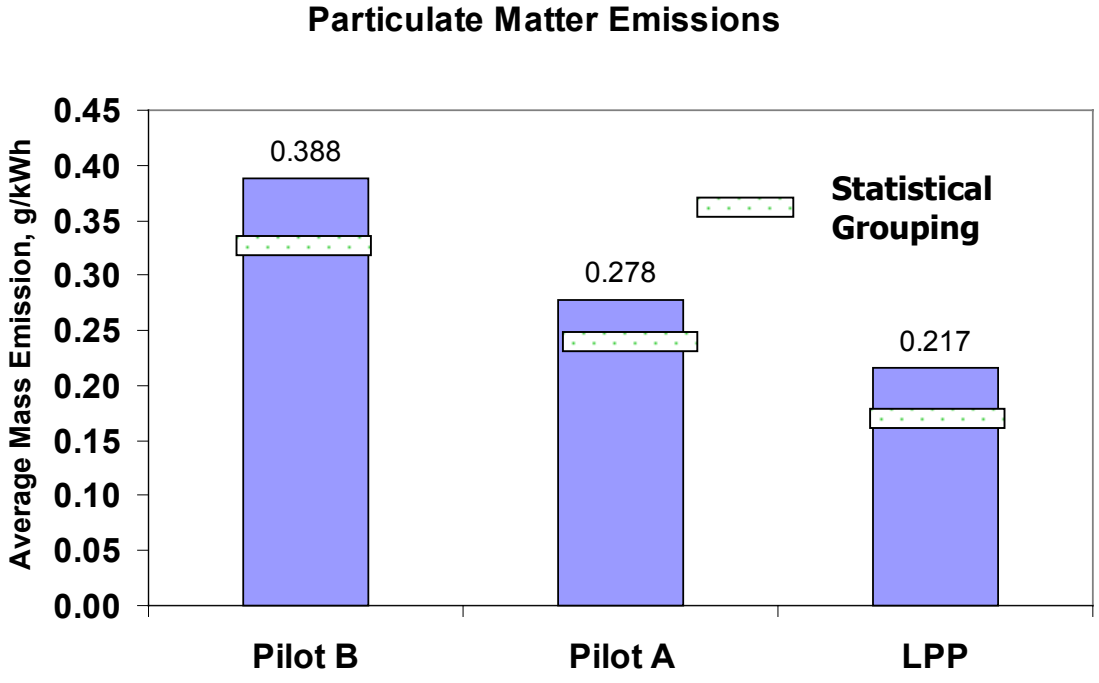


Figure 45. Pilot Condition Average Total Particulate Mass Emissions for Fuels and Modes (g/kWh)

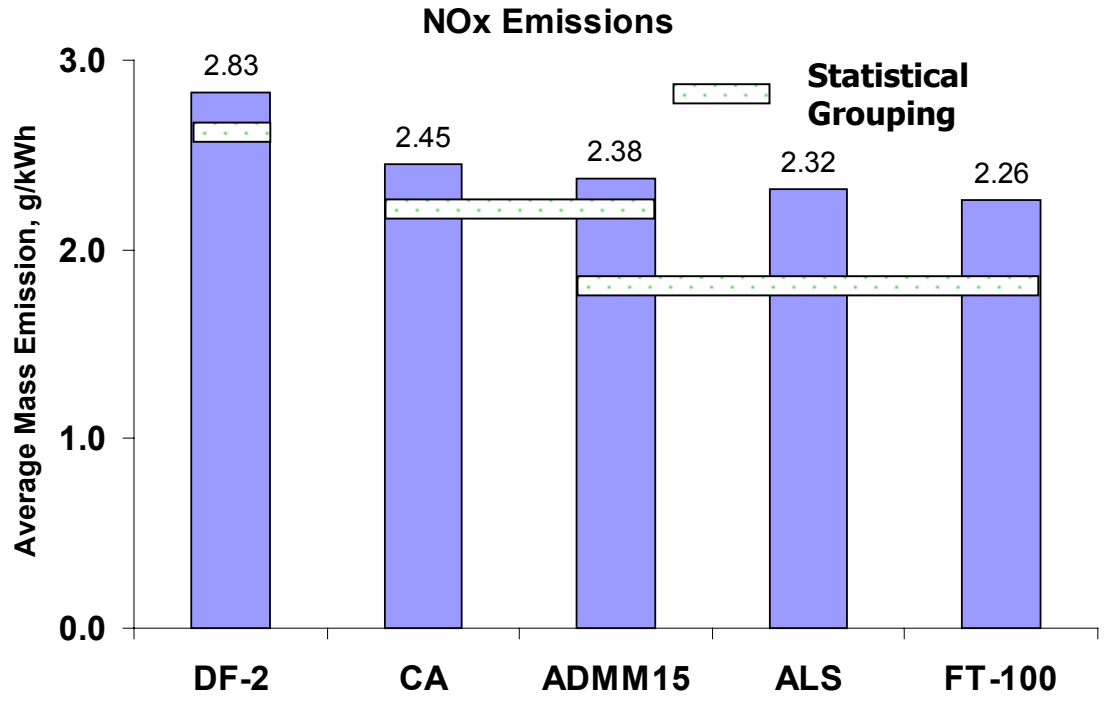


Figure 46. Test Fuel Average NO_X Mass Emissions for Pilot Conditions and Modes (g/kWh)

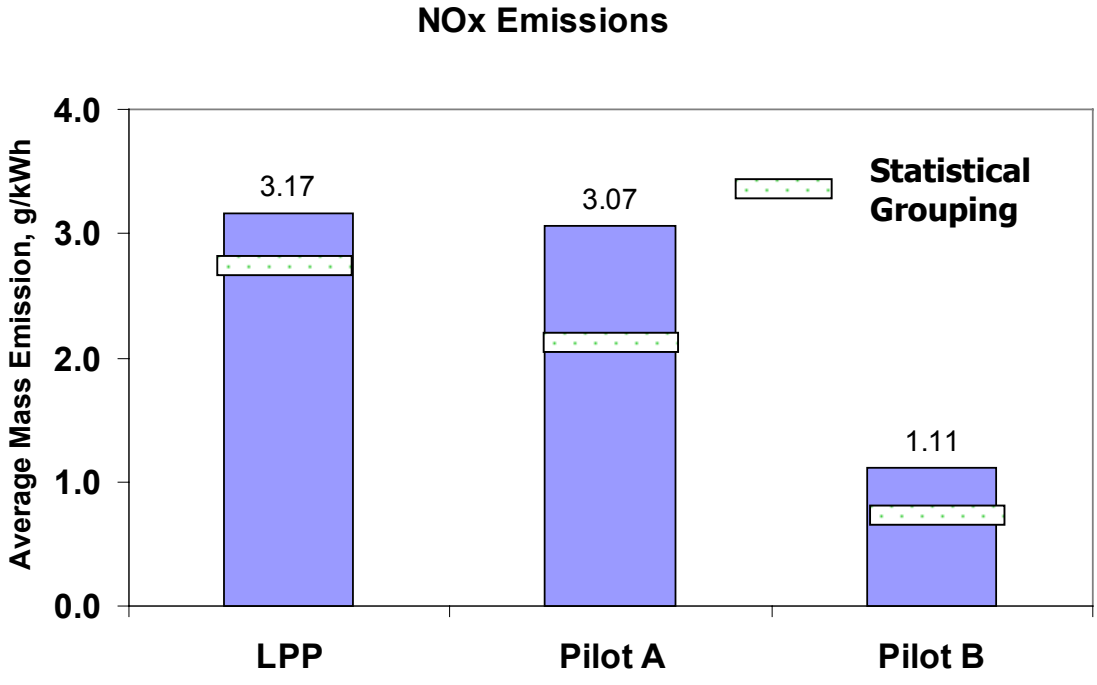


Figure 47. Pilot Condition Average NO_X Mass Emissions for Fuels and Modes (g/kWh)

Modes 10 and 11 are significantly different from one another with respect to the average NO_X.

The average NO_X for the DF-2 fuel is significantly different than the remaining four fuels at the LPP condition. This trend does not exist at the Pilot A or Pilot B conditions.

A significant interaction exists between the pilot condition and the modes. The difference in the average NO_X between modes 10 and 11 at the LPP condition is larger than the difference at the Pilot B condition.

A significant interaction exists between the mode and fuel levels. The difference in the average NO_X between modes 10 and 11 is the largest at the DF-2 fuel and the smallest at the FT-100 fuel.

7.1.3 Fuel Impact on HC

Statistically significant differences exist for the average BSHC among the fuels, modes, pilot conditions, and interactions. The average BSHC at the FT-100, CA, and DF-2 fuels are all significantly different from one another. The average BSHC for the ADMM15 and ALS fuels are not significantly different from one another, but are different from the other 3 fuels as shown in Figure 48.

Figure 49 shows the least-square means for the pilot conditions for hydrocarbon emissions. Average BSHC at the Pilot A and Pilot B conditions are not significantly different from one another, but both are different from the average BSHC at the LPP condition.

The average BSHC at modes 10 and 11 are significantly different from one another.

The CA and DF-2 fuels have significantly different trends in the average BSHC at the Pilot B condition than at the other two pilot conditions.

Mode 11 demonstrates a constant trend with respect to the average BSHC. However, mode 10 shows significantly different average BSHC at Pilot Conditions A and B than at the LPP condition.

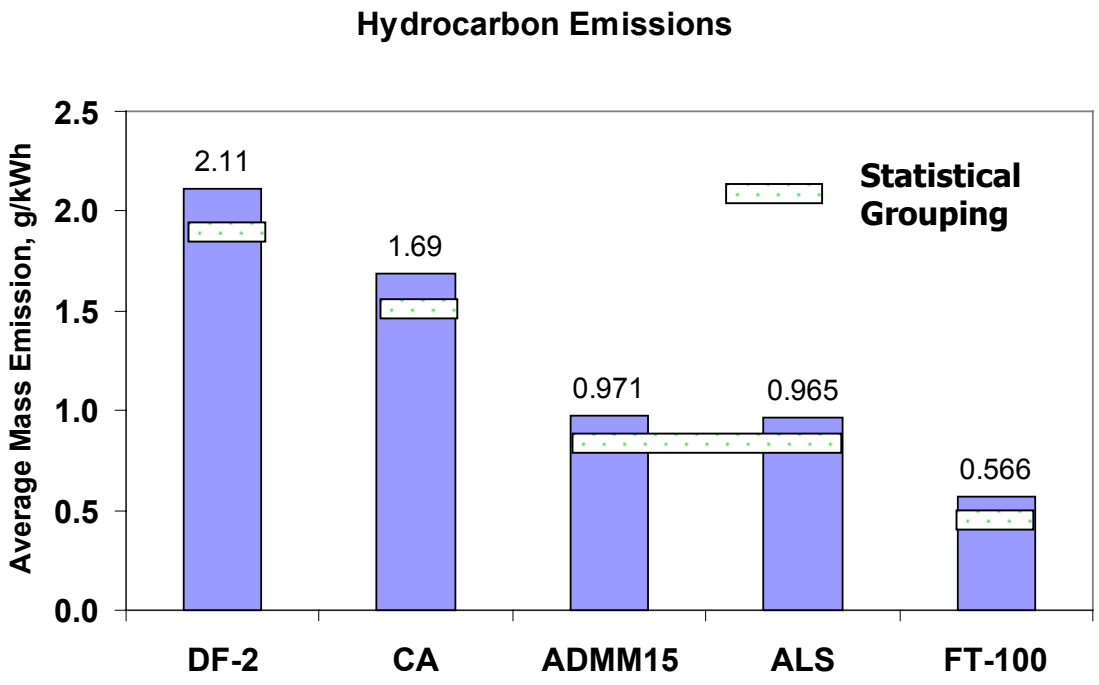


Figure 48. Test Fuel Average Hydrocarbon Mass Emissions for Pilot Conditions and Modes (g/kWh)

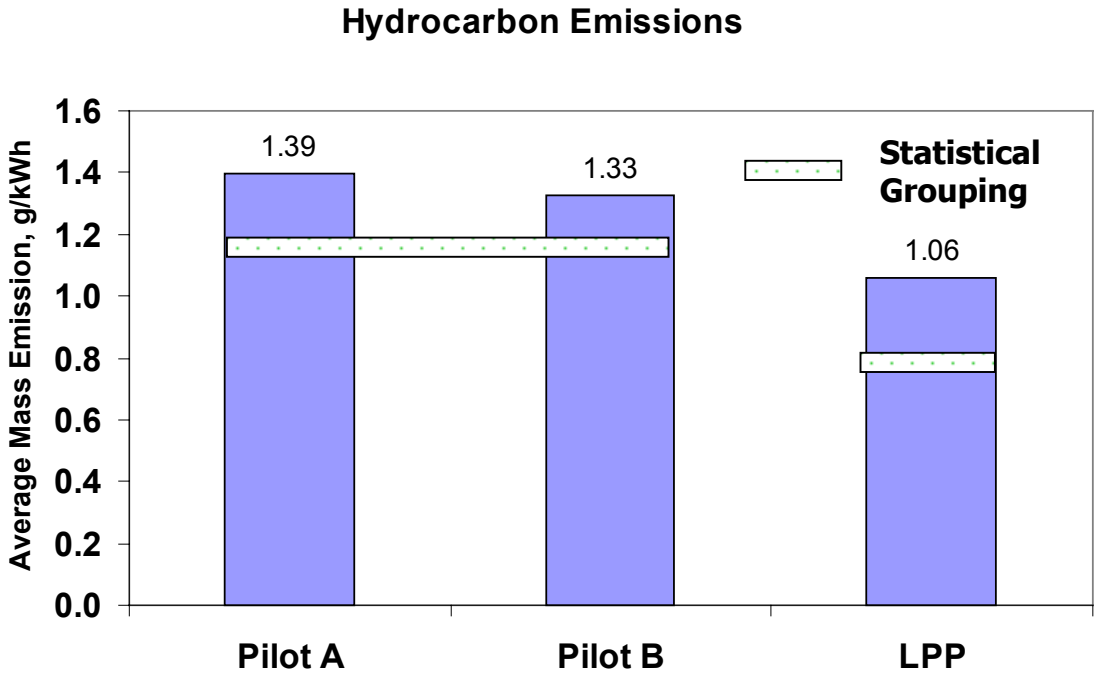


Figure 49. Pilot Condition Average Hydrocarbon Mass Emissions for Fuels and Modes (g/kWh)

A significant interaction exists between the mode and fuel levels. The differences in the average BSHC between modes 10 and 11 are largest at the CA and DF-2 fuels and the smallest at the FT-100 fuel.

7.1.4 Fuel Impact on CO

Statistically significant differences were noted in the average BSCO among the fuels, pilot condition, modes, two-way interactions, and three-way interaction. In Figure 50 it can be seen all five fuels are significantly different from one another with respect to the average BSCO. Figure 51 shows all three pilot conditions are significantly different from one another with respect to the average BSCO.

Modes 10 and 11 are significantly different from one another with respect to the average BSCO.

The trend in the average BSCO for the ADMM15 fuel is significantly different across the pilot conditions than the trends for the remaining four fuels.

Mode 11 demonstrates a constant trend with respect to the average BSCO. However, mode 10 shows significantly different average BSCO at all three pilot conditions.

A significant interaction exists between the mode and fuel levels. The difference in the average BSCO between modes 10 and 11 is the largest at fuels CA and DF-2 and the smallest at the FT-100 fuel.

7.1.5 Fuel Impact on CO_2

Statistically significant differences were apparent in the average $BSCO_2$ among the fuels, modes, pilot conditions, and three-way interaction. The average $BSCO_2$ is shown in Figure 52. The average $BSCO_2$ for the FT-100, ALS, and ADMM15 fuels are significantly different from each other and the remaining two fuels. The average $BSCO_2$ for the CA and DF-2 fuels are not significantly different from one another.

The average $BSCO_2$ in Figure 53 show that the Pilot B condition is significantly different than the LPP condition.

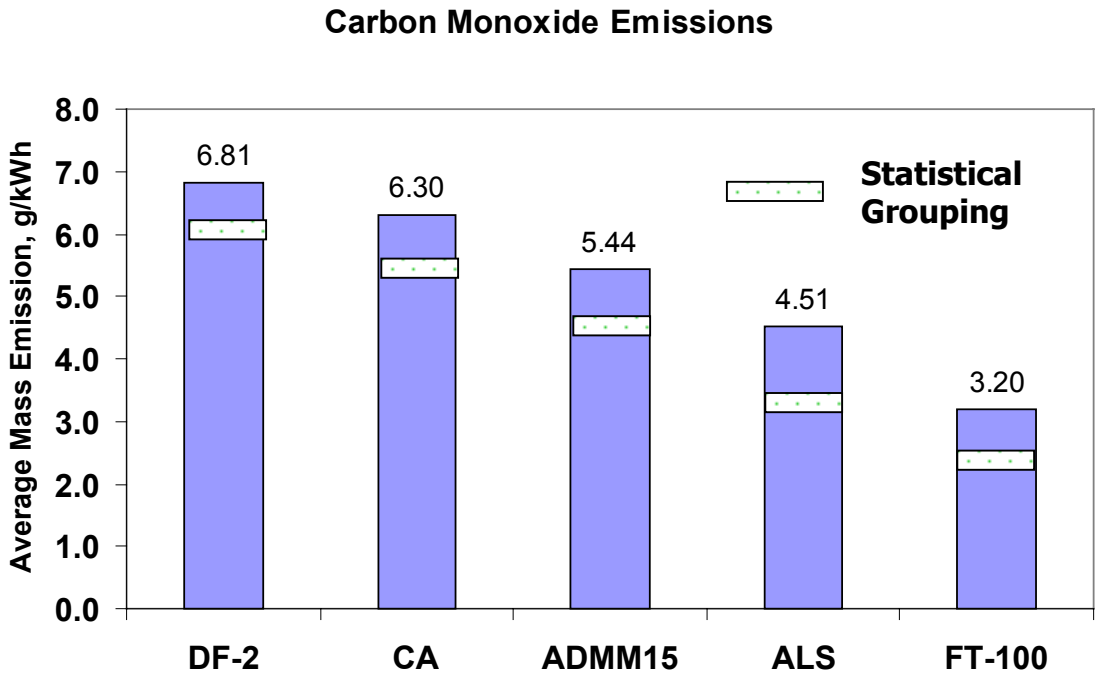


Figure 50. Test Fuel Average Carbon Monoxide Mass Emissions for Pilot Conditions and Modes (g/kWh)

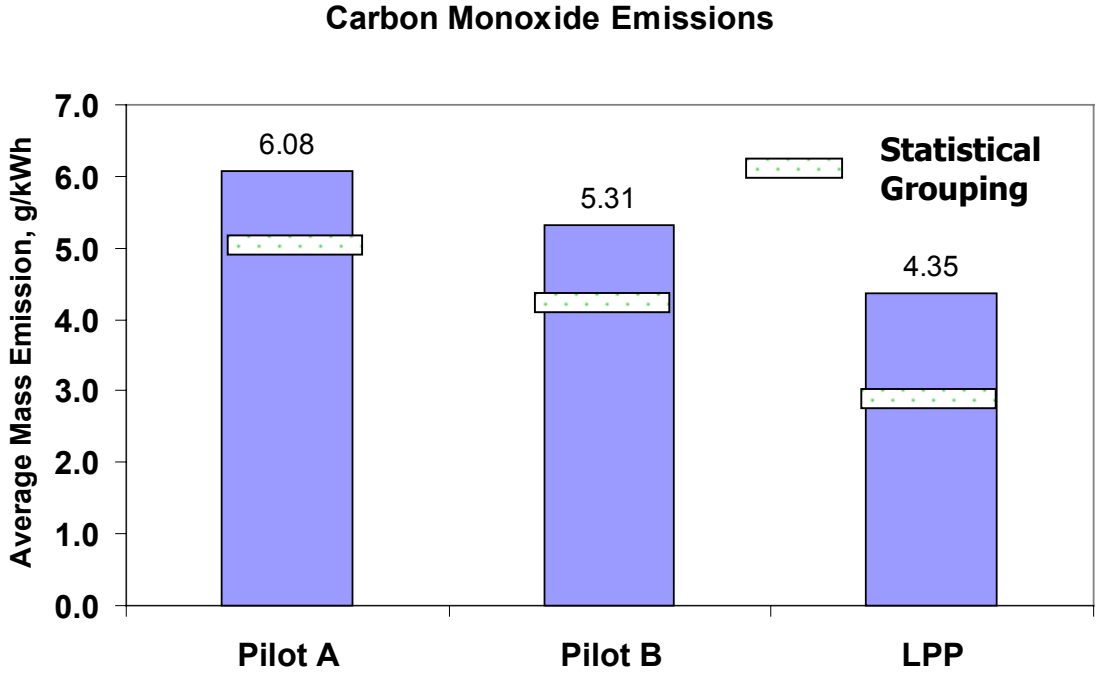


Figure 51. Pilot Condition Average Carbon Monoxide Mass Emissions for Fuels and Modes (g/kWh)

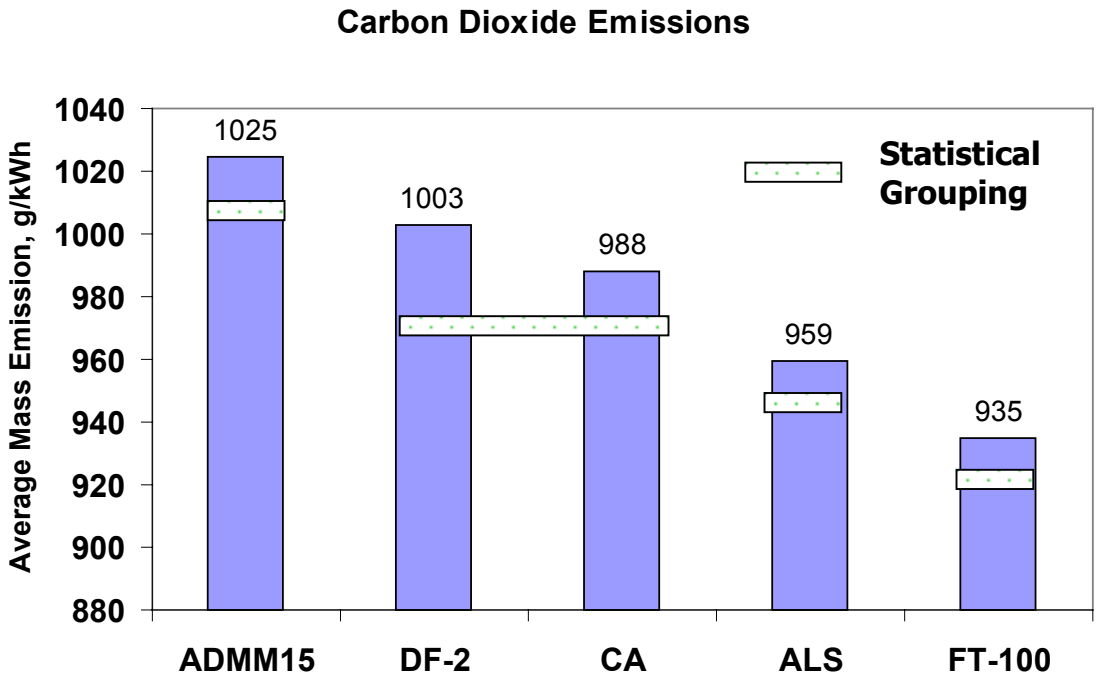


Figure 52. Test Fuel Average Carbon Dioxide Mass Emissions for Pilot Conditions and Modes (g/kWh)

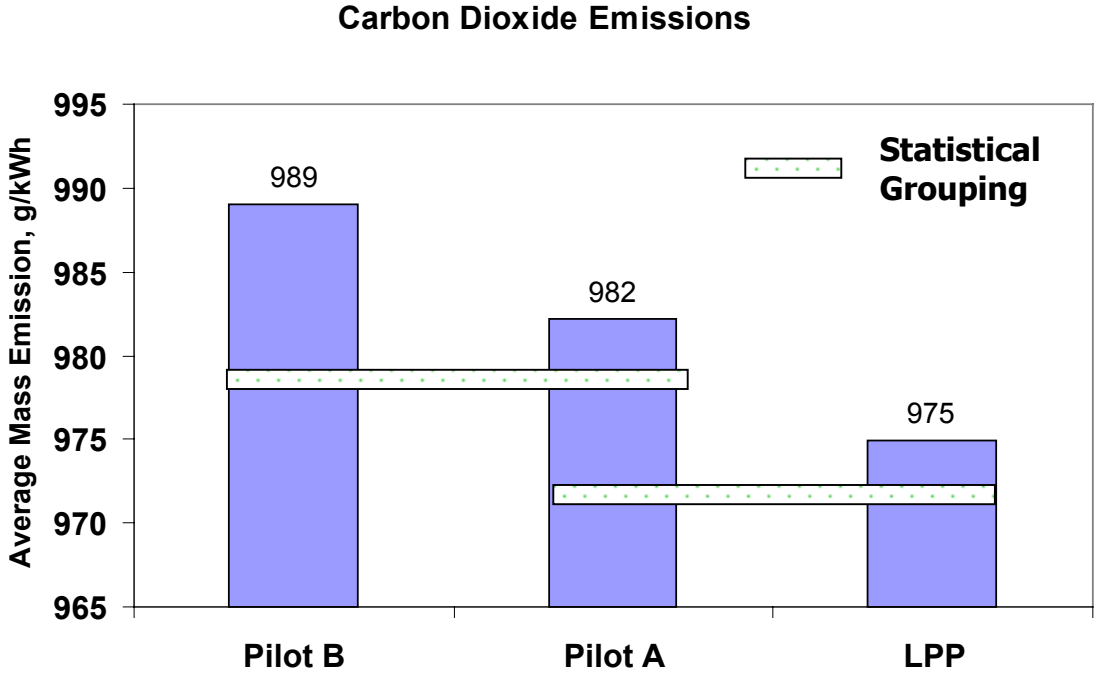


Figure 53. Pilot Condition Average Carbon Dioxide Mass Emissions for Fuels and Modes (g/kWh)

Modes 10 and 11 are significantly different from one another with respect to the average $BSCO_2$.

No significant differences exist among the fuel and pilot condition combinations, the mode and pilot condition combinations, and the mode and fuel combinations with respect to the average $BSCO_2$.

7.1.6 Fuel Impact on SOF of Particulate

Statistically significant differences exist in the average BSSOF among the fuels, modes, pilot conditions, all two-factor interactions, and the three-factor interaction between the fuel*mode*pilot condition. The average BSSOF for the FT-100, CA, and DF-2 fuels are significantly different from one another and the remaining two fuels, as shown in Figure 54. The average BSSOF for the ADMM15 and ALS fuels are not significantly different from one another.

As seen in Figure 55 the average BSSOF for the Pilot A condition is significantly different from the Pilot B condition, but not different than the LPP condition.

The average BSSOF for modes 10 and 11 are statistically significant from one another.

The trend in the average BSSOF across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average BSSOF for the DF-2 fuel at the Pilot A and Pilot B conditions are significantly different than the other four fuels.

The average BSSOF at the LPP and Pilot A conditions for Mode 10 are significantly different than those at Mode 11. There is not a significant difference in the average BSSOF between the two modes at the Pilot B condition.

The trends in the average BSSOF across the two modes are different at fuels ADMM15 and CA. There does not appear to be differences in the average BSSOF for the two modes at the ALS, DF-2 or FT-100 fuels.

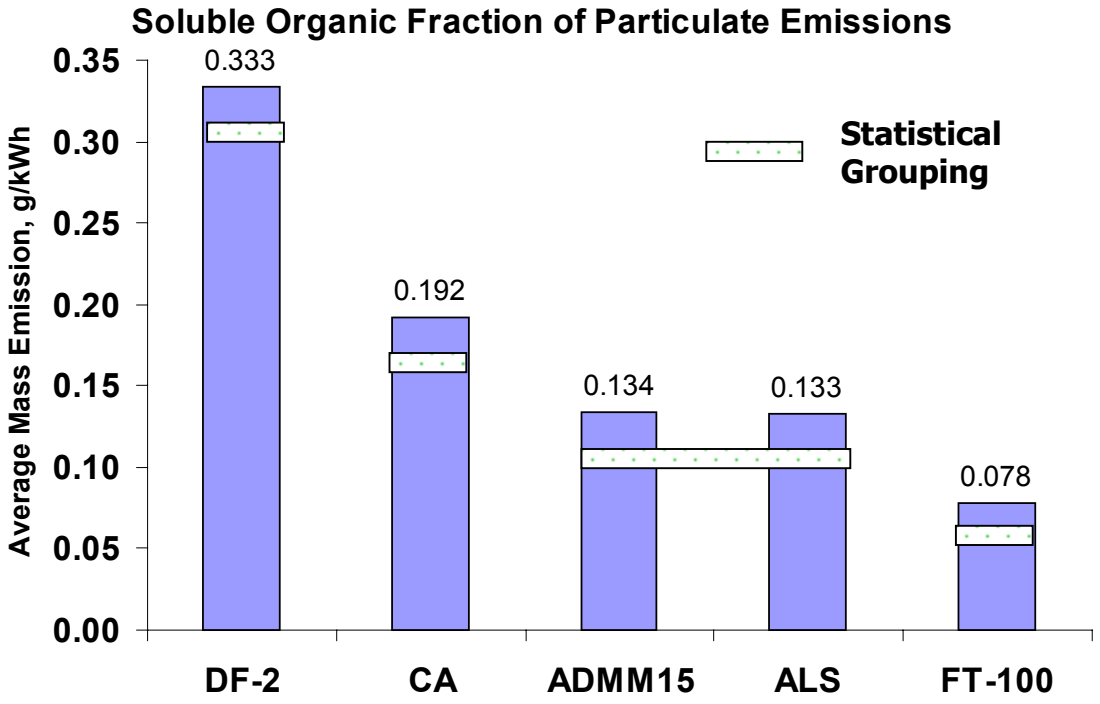


Figure 54. Test Fuel Average SOF of Particulate Mass Emissions for Pilot Conditions and Modes (g/kWh)

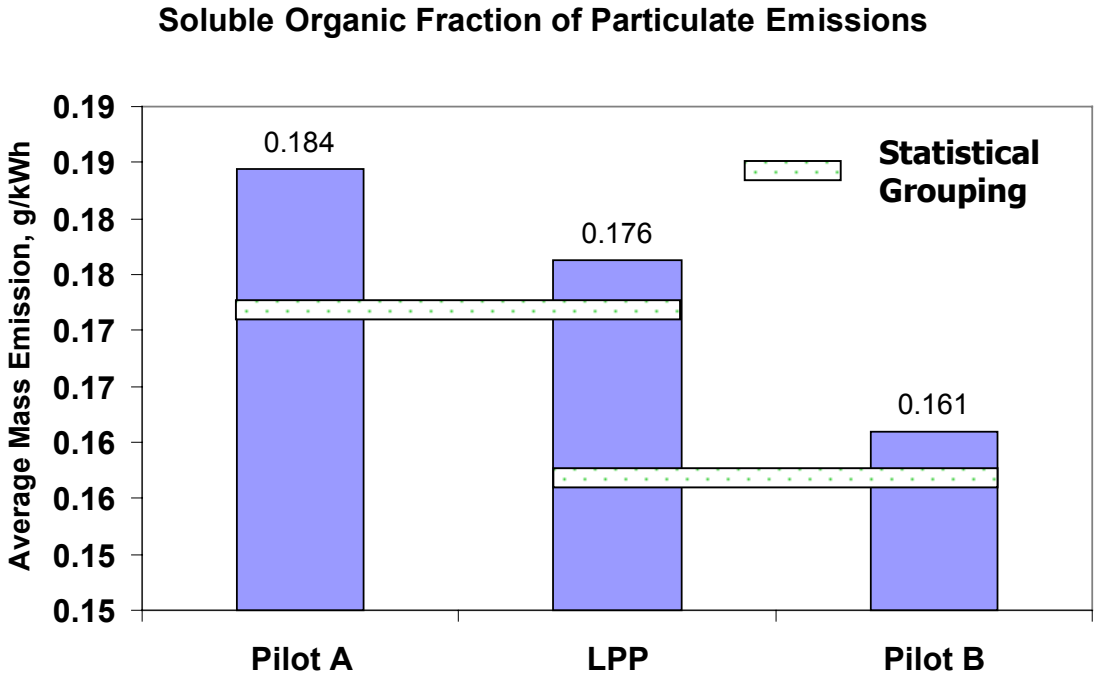


Figure 55. Pilot Condition Average SOF of Particulate Mass Emissions for Fuels and Modes (g/kWh)

The ratio of SOF to total particulate averaged across the test modes and pilot conditions is shown in Figure 56 for the test fuels. Although ADMM15 and FT-100 have statistically similar total PM response, the SOF for the two fuels are statistically different across the pilot conditions. The oxygenated fuel, ADMM15, has a significantly higher soluble organic fraction. From Figure 56 it is also seen that FT-100 has a smaller portion of soluble particulate matter than the other fuels.

Figure 57 shows the effect of pilot condition on the ratio of SOF to total particulate. Of interest is as the total particulate changes for the pilot conditions, the ratio of SOF /PM changes inversely. Figure 58 shows the average SOF/PM ratio plotted with the average exhaust temperature for each pilot condition. The data suggests the SOF is related to the exhaust temperature. Injection timing, EGR levels, and combustion characteristics all contribute to variations in the exhaust temperature for a constant BMEP.

7.2 Fuel Impact on Four Toxic Air Pollutants

Several statistically significant trends, at 95% confidence, were apparent from an ANOVA of the pilot fuel injection condition emissions data. Table 25 summarizes the general rank order of the fuels for the CAA toxic air pollutant mass emissions across the three pilot control conditions and two modes. The table displays the fuels rank from highest response to lowest response for the Least-Square means of the analysis. Statistically significant similar fuel groupings are also shown for each emission response in Table 25.

Table 25 includes the pilot condition severity across fuels and modes for each toxic air pollutant. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average toxic emissions at each pilot condition. The general trend for pilot condition severity suggests LPP operation results in the lowest CAA toxic emissions.

The mode severity across fuels and pilot condition for each toxic air pollutant is also in Table 25. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average toxic emissions at each mode. The general trend is mode 10 has significantly higher emissions than mode 11 across the fuels and pilot conditions. The Fuel*Pilot, Fuel*Mode, Pilot*Mode, and Fuel*Pilot*Mode interactions are indicated in Table 25 for each toxic air pollutant.

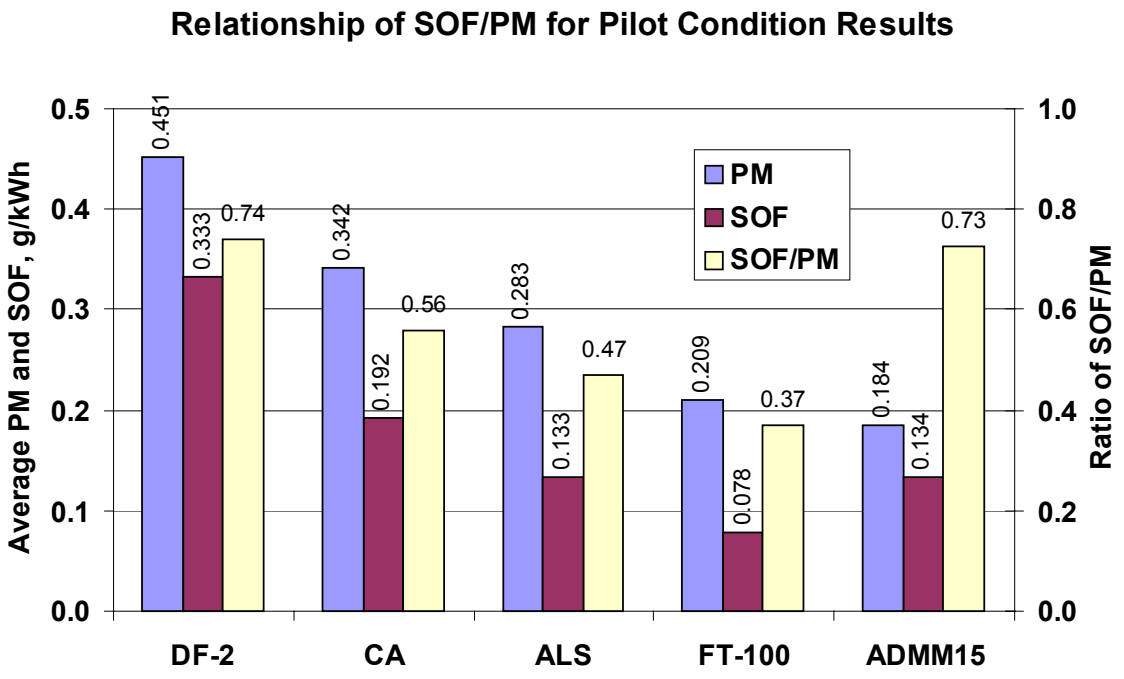


Figure 56. Test Fuel Average SOF/PM Ratio for Pilot Conditions and Modes

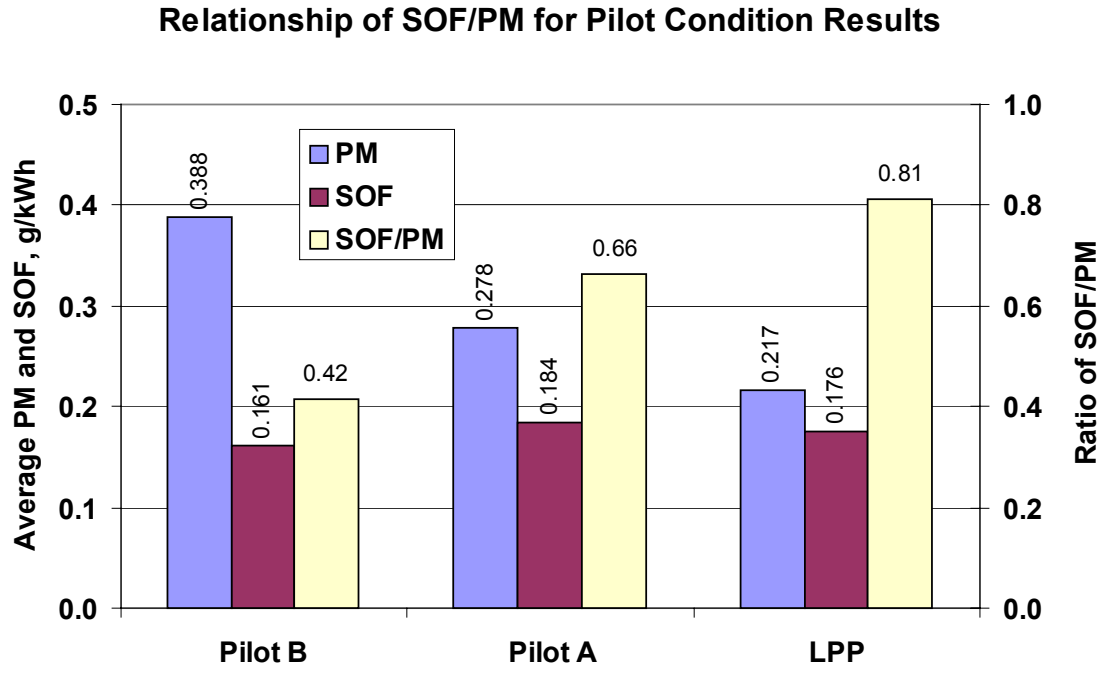


Figure 57. Pilot Condition Average SOF/PM Ratio for Test Fuels and Modes

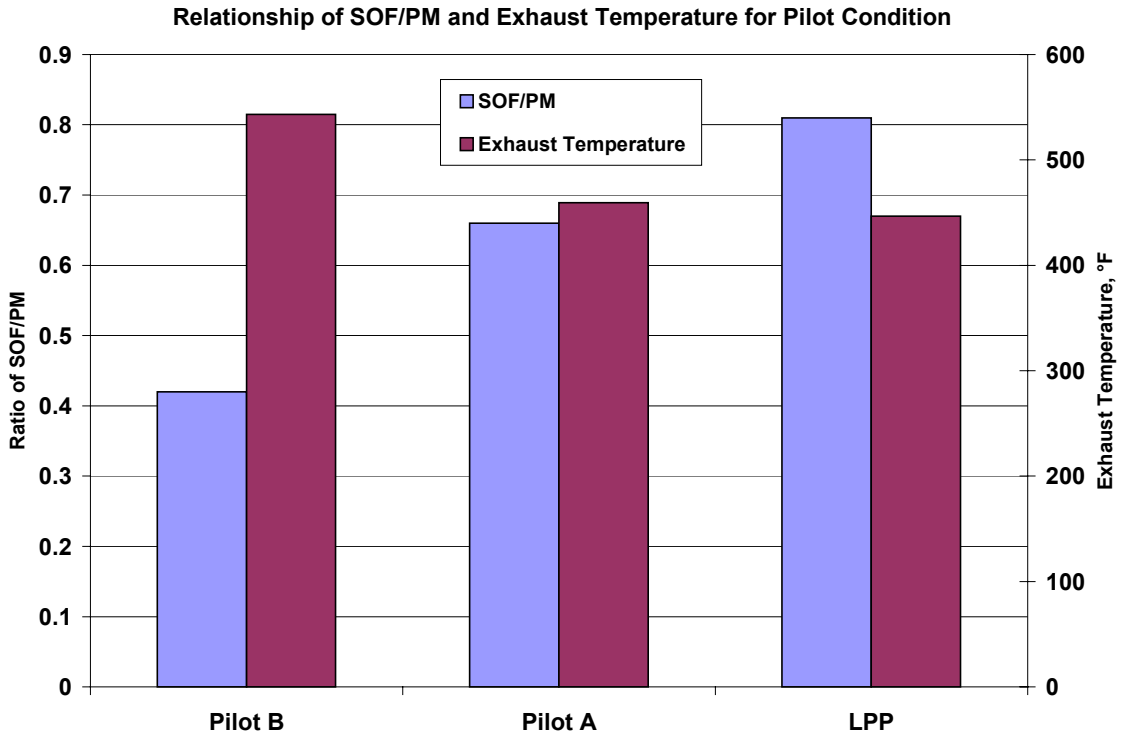


Figure 58. Pilot Condition Average SOF/PM and Exhaust Temperature for Test Fuels and Modes

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the pilot fuel injection study, and refer to the results in Table 25. The ANOVA tables for the pilot fuel injection evaluations can be found in Appendix F.

7.2.1 Benzene

Statistically significant differences were noted in the average benzene among the fuels, modes, pilot conditions, and the fuel*pilot condition interaction. The average benzene for the ALS, CA, and DF-2 fuels are significantly different from one another and the remaining two fuels, Figure 59. The average benzene for the ADMM15 and FT-100 fuels are not significantly different from one another.

The toxic air pollutant benzene response in Figure 60 indicates the two pilot conditions are statistically similar, but different from LPP operation with pilot turned off.

Table 25. Clean Air Act Toxic Compound Mass Emissions (mg/kWh) for Pilot Fuel Injection Study										
Response	Five Fuels, Three Pilot Conditions, Modes 10 and 11									
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Pilot Condition	LS Means[1]	Significant Pilot Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interactions
Benzene	DF-2	11.73	A	Pilot A	8.662	A	10	8.068	A	Pilot*Fuel
	CA	9.671	B	Pilot B	7.977	A	11	6.648	B	
	ALS	7.340	C	LPP	5.435	B				
	ADMM15	4.351	D							
	FT-100	3.700	D							
1,3-Butadiene	DF-2	8.974	A	Pilot B	7.474	A	10	8.024	A	Pilot*Fuel Pilot*Mode Fuel*Mode
	CA	7.004	B	Pilot A	6.701	B	11	5.178	B	
	ADMM15	6.294	BC	LPP	5.628	C				
	ALS	5.561	CD							
	FT-100	5.171	D							
Formaldehyde	DF-2	655.5	A	Pilot A	564.7	A	10	619.2	A	Pilot*Fuel Pilot*Mode Fuel*Mode
	CA	478.3	B	Pilot B	493.1	B	11	358.2	B	
	ALS	472.5	B	LPP	408.3	C				
	ADMM15	458.3	B							
	FT-100	379.0	C							
Acetaldehyde	DF-2	225.2	A	Pilot A	196.3	A	10	211.1	A	Pilot*Fuel Pilot*Mode
	ALS	175.1	B	Pilot B	159.6	B	11	127.3	B	
	CA	169.8	B	LPP	151.7	B				
	FT-100	139.8	C							
	ADMM15	136.0	C							

[1]Factor levels listed from highest to lowest least squares mean

[2]Letters designate groups of factor means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

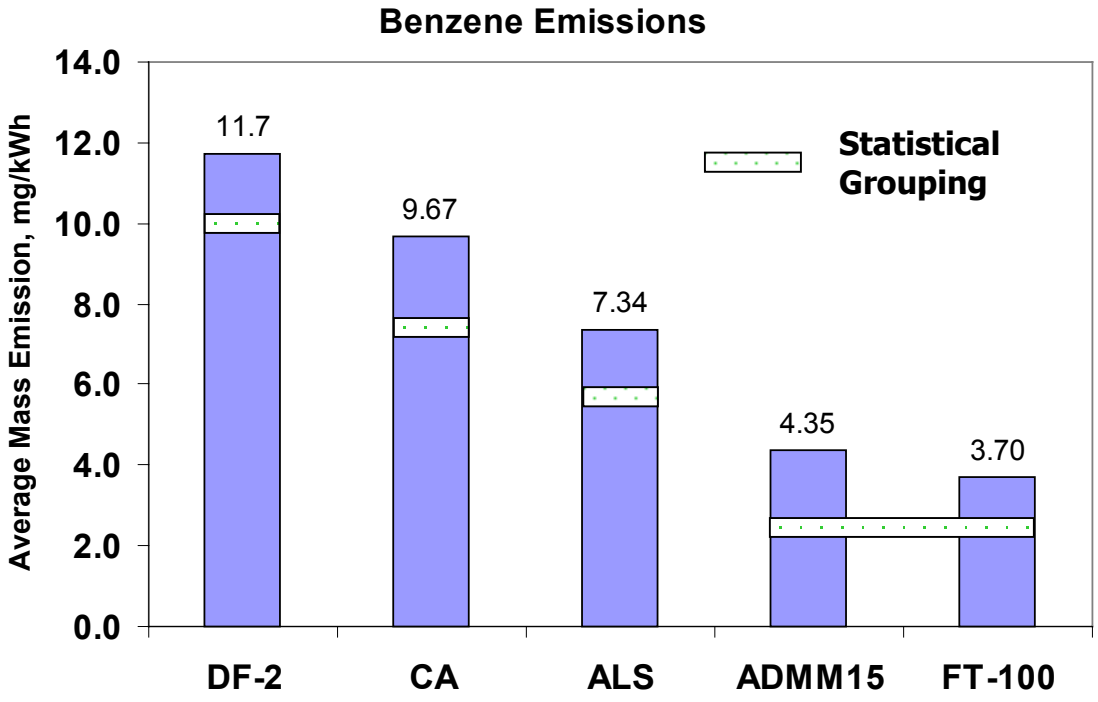


Figure 59. Test Fuel Average Benzene Mass Emissions for Pilot Conditions and Modes (mg/kWh)

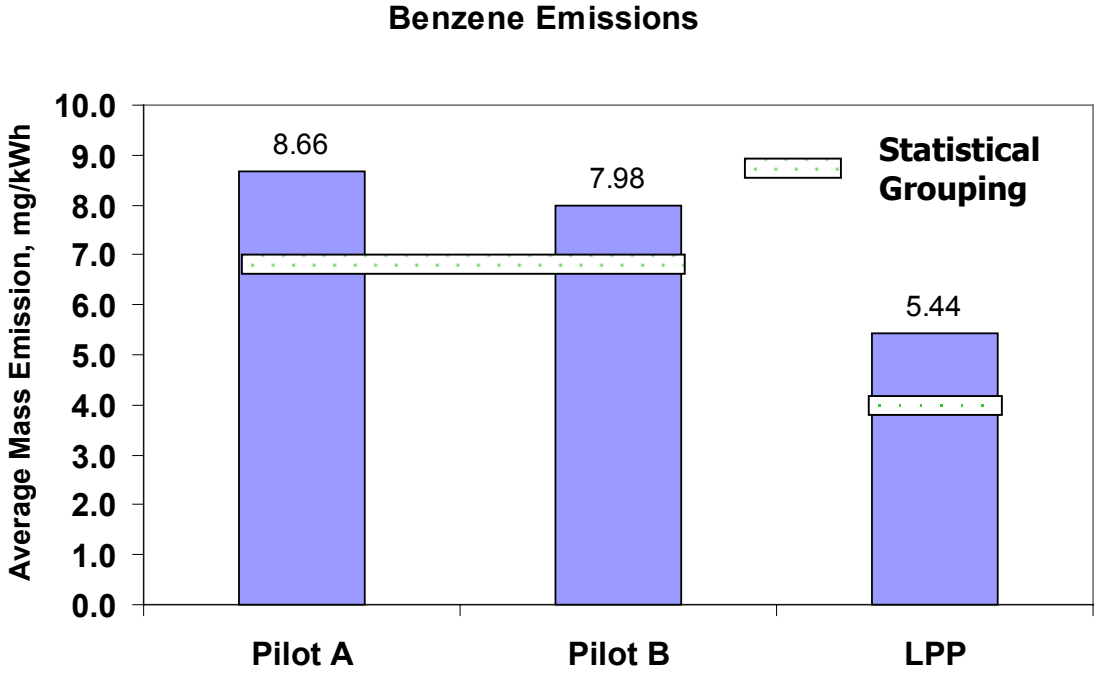


Figure 60. Pilot Condition Average Benzene Mass Emissions for Test Fuels and Modes (mg/kWh)

The average benzene for modes 10 and 11 are significantly different from one another.

The trend in the average benzene across the pilot conditions for the DF-2 and CA fuels is significantly different than the trends for the remaining three fuels. The average benzene for the DF-2 fuel at the Pilot B condition is significantly different than the other four fuels, but not at the LPP condition. Also, the Pilot A condition demonstrates that the average benzene for the DF-2 and CA fuels are not significantly different from one another.

There is no significant interaction in the average benzene among the mode and pilot condition combinations.

There is no significant interaction in the average benzene among the mode and fuel combinations.

7.2.2 1,3-butadiene

Statistically significant differences were apparent in the average 1,3-butadiene among the fuels, modes, pilot conditions, and two-way interactions. There are several distinct fuel groupings with respect to the average 1,3-butadiene. The average 1,3-butadiene in Figure 61 for the DF-2 fuel is significantly different than the remaining four fuels. The FT-100 fuel is significantly different than the ADMM15 and CA fuels, but not significantly different than the ALS fuel. Also, the average 1,3-butadiene for the CA fuel is significantly different than the ALS fuel.

All three pilot conditions shown in Figure 62 are significantly different from one another with respect to the average 1,3-butadiene.

The average 1,3-butadiene for mode 10 is significantly different than mode 11.

The trends in the average 1,3-butadiene across the pilot conditions for the DF-2 and FT-100 fuels appear similar. However, the ALS fuel demonstrates an almost constant average 1,3-butadiene across all three pilot conditions while the CA fuel shows a significant decrease from the Pilot A to Pilot B conditions.

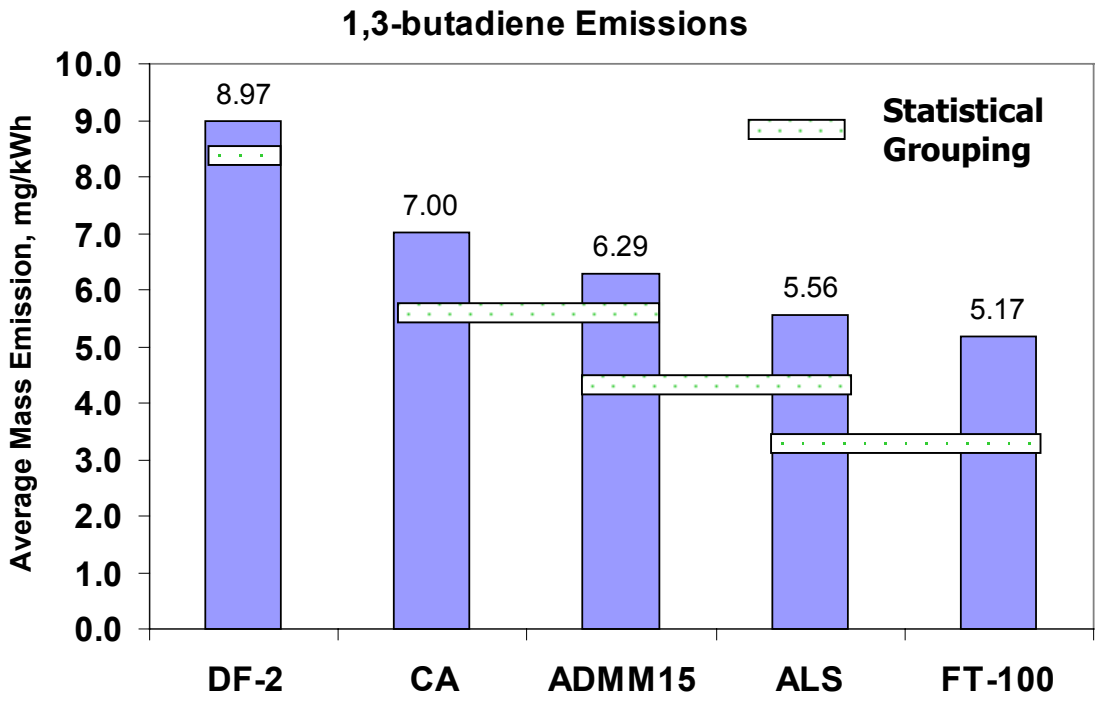


Figure 61. Test Fuel Average 1,3-butadiene Mass Emissions for Pilot Conditions and Modes (mg/kWh)

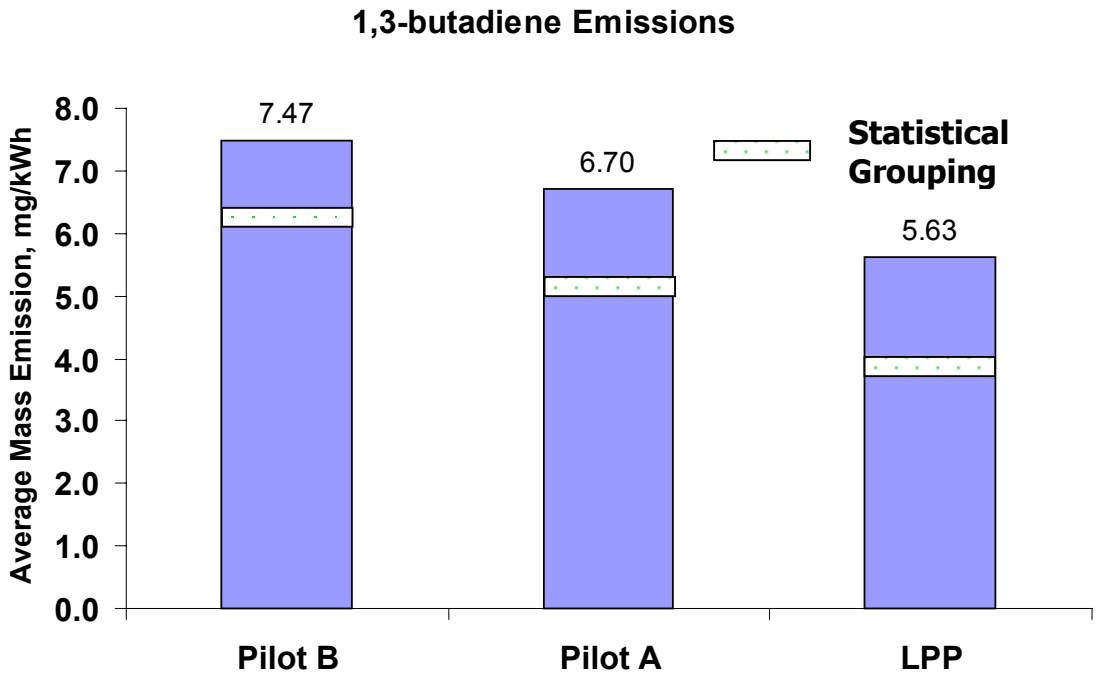


Figure 62. Pilot Condition Average 1,3-butadiene Mass Emissions for Test Fuels and Modes (mg/kWh)

A significant interaction exists between the pilot condition and the modes. The difference in the average 1,3-butadiene between the two modes at the LPP condition is smaller than the differences at the Pilot A and Pilot B conditions.

A significant interaction exists between the mode and the fuel levels. The difference in the average 1,3-butadiene between modes 10 and 11 is the largest at the DF-2 fuel and the smallest at the ALS fuel.

7.2.3 Formaldehyde

Statistically significant differences exist in the average formaldehyde among the fuels, modes, pilot conditions, and two-way interactions. Figure 63 shows there are three distinct fuel groupings with respect to the average formaldehyde. Fuels FT-100 and DF-2 are significantly different from one another and the remaining three fuels. The ADMM15, ALS, and CA fuels are not significantly different from one another, but are significantly different than the other two fuels.

All three pilot conditions in Figure 64 are significantly different from one another with respect to the average formaldehyde.

The average formaldehyde for mode 10 is significantly different than mode 11.

The trends in the average formaldehyde across the pilot conditions for the CA and ALS fuels appear similar. However, the ADMM15 fuel demonstrates an increase in the average formaldehyde from the Pilot A to the Pilot B conditions, whereas the CA and ALS fuels showed a decrease.

A significant interaction exists between the pilot conditions and the modes. The difference in the average formaldehyde between the two modes at the LPP condition is smaller than the differences at the Pilot A and Pilot B conditions.

A significant interaction exists between the mode and the fuel levels. The difference in the average formaldehyde between modes 10 and 11 is the largest at the DF-2 fuel and the smallest at the ALS fuel.

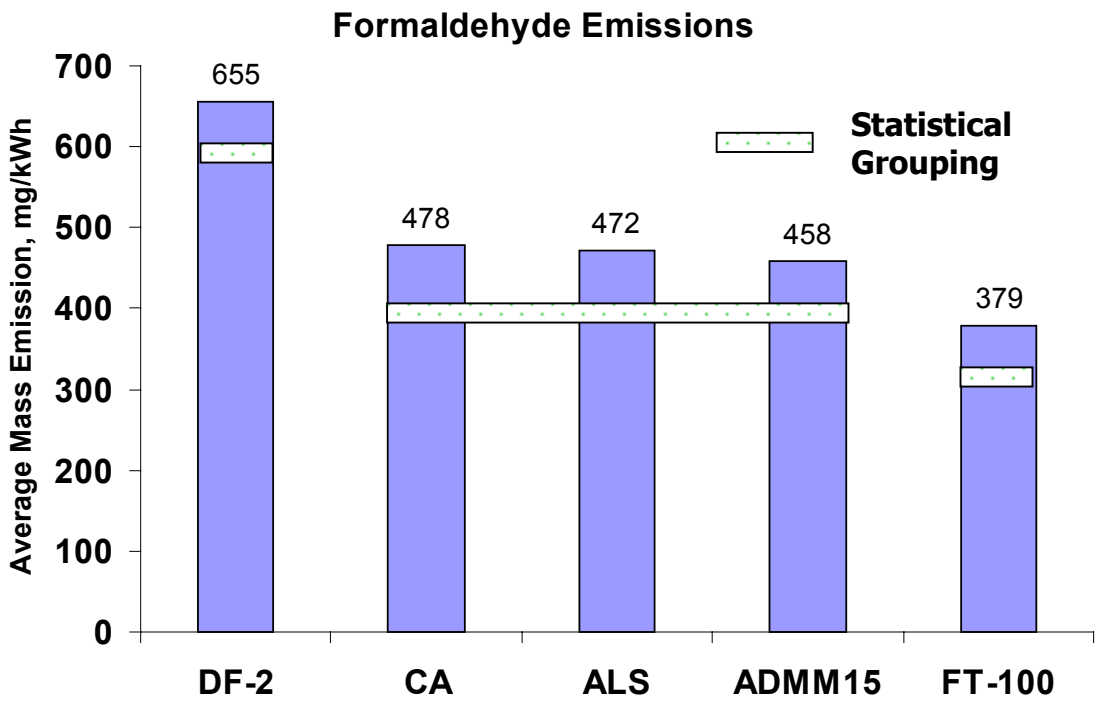


Figure 63. Test Fuel Average Formaldehyde Mass Emissions for Pilot Conditions and Modes (mg/kWh)

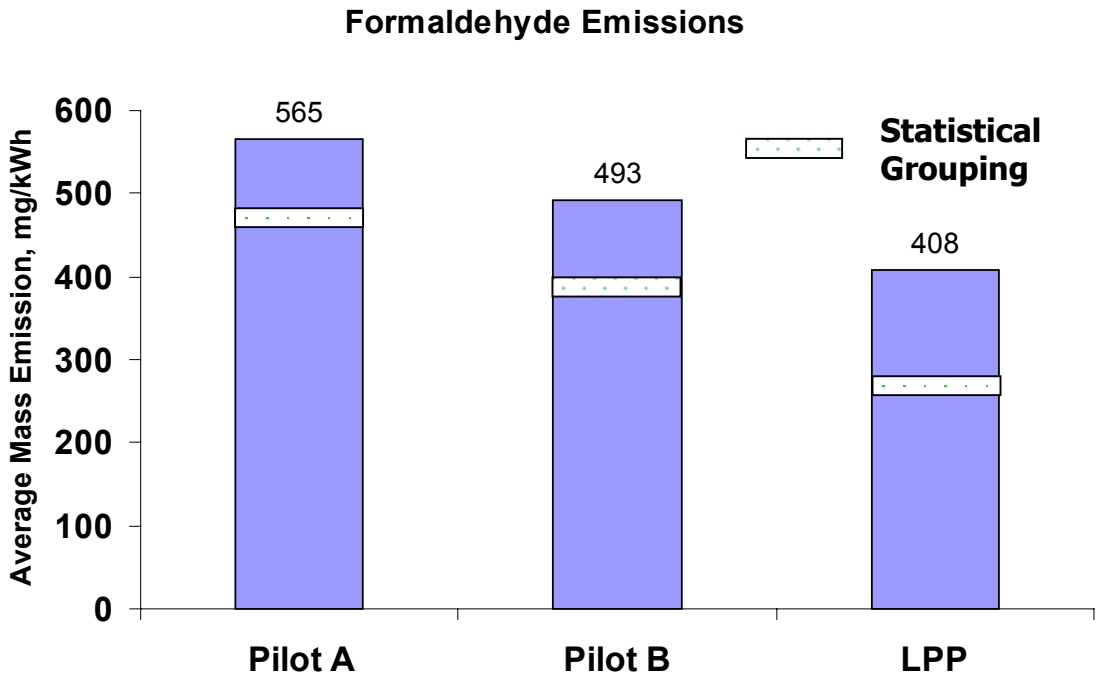


Figure 64. Pilot Condition Average Formaldehyde Mass Emissions for Test Fuels and Modes (mg/kWh)

7.2.4 Acetaldehyde

Statistically significant differences were apparent in the average acetaldehyde among the fuels, modes, pilot conditions, and some two-way interactions. There are three distinct fuel groupings in Figure 65 with respect to the average acetaldehyde. The DF-2 fuel is significantly different from the remaining four fuels. The ADMM15 and FT-100 fuels are not significantly different from one another, but are different from the other fuels. Also, the CA and ALS fuels are not significantly different from one another, but are different from the other fuels.

The average acetaldehyde in Figure 66 for the LPP and Pilot B conditions are not significantly different from one another, but are different from the Pilot A condition.

The average acetaldehyde for mode 10 is significantly different than mode 11.

The trends in the average acetaldehyde across the pilot conditions for the CA and ALS fuels appear similar. While the ADMM15 fuel demonstrates an increase in the average acetaldehyde from the Pilot A to Pilot B conditions, the CA and ALS fuels showed a decrease.

A significant interaction exists between the pilot condition and the modes. The difference in the average acetaldehyde between the two modes at the LPP condition is smaller than the differences at the Pilot A and Pilot B conditions.

There is no significant interaction in the average acetaldehyde among the fuel and mode combinations.

7.3 Fuel Impact on Particulate Soluble Extract PAH Species

Table 26 summarizes the general rank order of the fuels for the particulate soluble extract PAH mass emissions across the three pilot control conditions and two modes. The table displays the fuels rank from highest response to lowest response for the least-square means for the analysis. In general, ADMM15 and FT-100 are in the lowest statistically significant emissions grouping. Statistically significant similar fuel groupings are also shown for each emission response in Table 26.

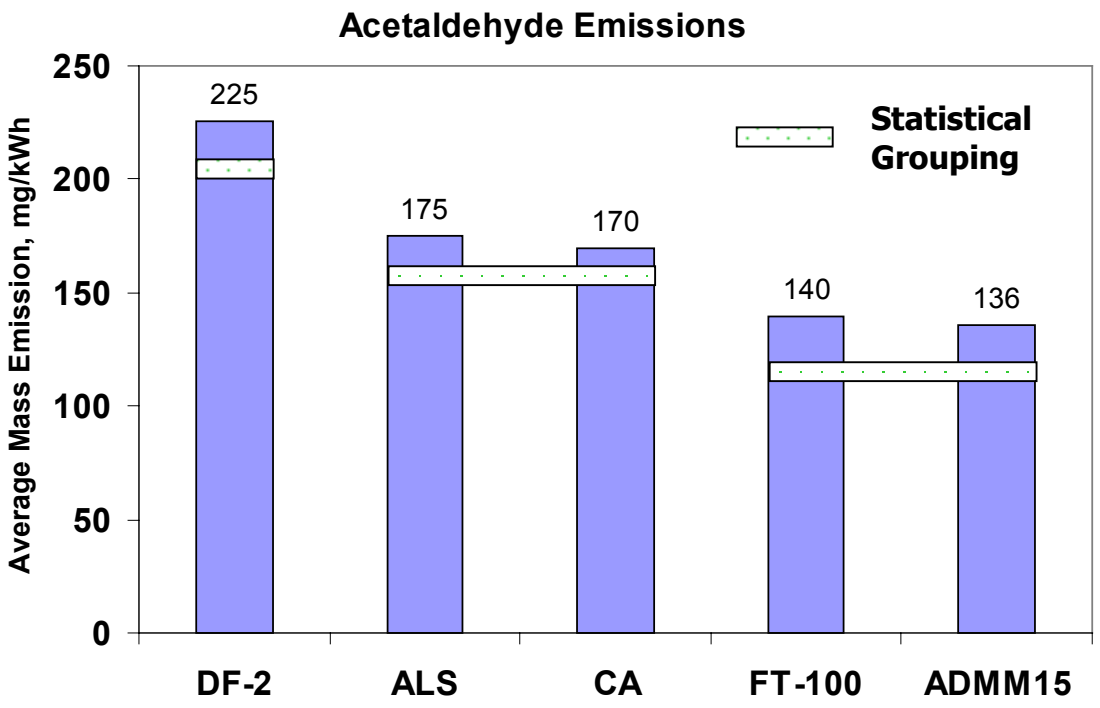


Figure 65. Test Fuel Average Acetaldehyde Mass Emissions for Pilot Conditions and Modes (mg/kWh)

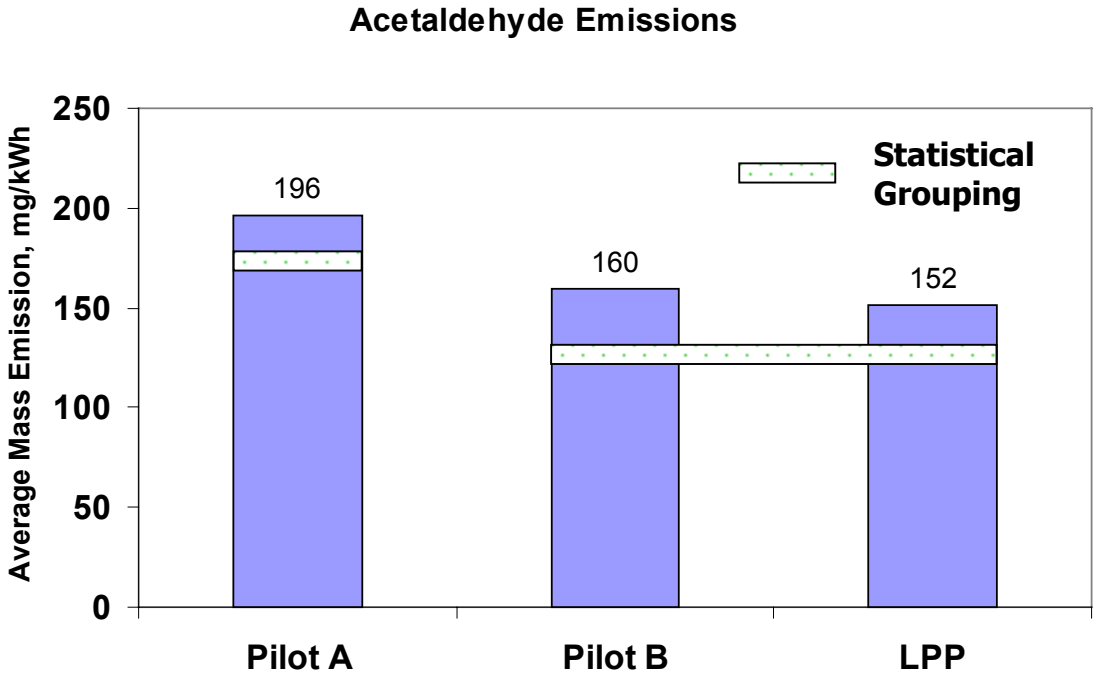


Figure 66. Pilot Condition Average Acetaldehyde Mass Emissions for Test Fuels and Modes (mg/kWh)

Table 26. Soluble Phase PAH Mass Emissions (µg/kWh) for Pilot Fuel Injection Study										
Response	Five Fuels, Three Pilot Conditions, Modes 10 and 11									
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Pilot Condition	LS Means[1]	Significant Pilot Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interactions
Phenanthrene	DF-2	262.9	A	Pilot B	145.8	A	10	106.3	NS	Pilot*Fuel
	ALS	90.80	B	Pilot A	113.4	A	11	105.3		
	CA	75.94	B	LPP	58.14	B				
	FT-100	52.92	B							
	ADMM15	46.48	B							
Anthracene	DF-2	8.800	A	Pilot B	6.441	A	10	4.811	NS	Pilot*Fuel Fuel*Mode Pilot*Fuel*Mode
	ALS	4.944	B	Pilot A	3.779	B	11	4.017		
	CA	4.508	B	LPP	3.022	B				
	FT-100	2.040	C							
	ADMM15	1.777	C							
Fluoranthene	DF-2	53.34	A	Pilot A	35.74	A	10	34.73	A	Pilot*Fuel Fuel*Mode
	CA	33.73	B	Pilot B	33.62	A	11	27.03	B	
	ALS	29.76	B	LPP	23.27	B				
	FT-100	18.84	C							
	ADMM15	18.71	C							
Pyrene	DF-2	86.69	A	Pilot A	42.34	A	10	41.14	A	Pilot*Fuel
	CA	33.44	B	Pilot B	41.79	A	11	34.73	B	
	ALS	32.75	B	LPP	29.67	B				
	ADMM15	21.70	BC							
	FT-100	15.09	C							
Naphthalene	CA	52.04	A	Pilot A	41.23	NS	10	44.49	A	NS
	DF-2	42.12	AB	LPP	39.56		11	34.53	B	
	FT-100	37.11	B	Pilot B	37.73					
	ALS	36.69	B							
	ADMM15	29.57	B							
Acenaphthylene	FT-100	1.402	A	Pilot B	1.517	A	11	1.116	NS	Pilot*Fuel Pilot*Mode Fuel*Mode Pilot*Fuel*Mode
	ALS	1.070	AB	Pilot A	0.9369	B	10	0.9928		
	DF-2	1.068	AB	LPP	0.7094	B				
	CA	1.038	AB							
	ADMM15	0.6940	B							

Table 26. Soluble Phase PAH Mass Emissions (µg/kWh) for Pilot Fuel Injection Study (contd)										
Response	Five Fuels, Three Pilot Conditions, Modes 10 and 11									
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Pilot Condition	LS Means[1]	Significant Pilot Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interactions
Acenaphthene	CA	7.070	A	Pilot A	6.322	A	10	6.509	A	Pilot*Fuel
	ALS	6.209	AB	Pilot B	5.984	AB	11	5.055	B	
	DF-2	5.473	AB	LPP	5.040	B				
	ADMM15	5.159	B							
	FT-100	4.998	B							
Fluorene	ALS	11.92	A	Pilot B	10.53	NS	10	10.89	A	Pilot*Fuel
	DF-2	10.71	AB	Pilot A	10.22		11	8.758	B	
	CA	10.66	AB	LPP	8.723					
	ADMM15	8.466	BC							
	FT-100	7.376	C							
Benzo[a]anthracene	DF-2	5.970	A	Pilot A	2.664	A	10	2.263	A	Pilot*Fuel
	CA	2.610	B	Pilot B	2.489	A	11	1.846	B	
	ALS	0.9662	C	LPP	1.012	B				
	ADMM15	0.4249	C							
	FT-100	0.3019	C							
Chrysene	DF-2	13.96	A	Pilot A	6.189	A	10	5.265	A	Pilot*Fuel
	CA	5.796	B	Pilot B	5.531	A	11	4.460	B	
	ALS	2.273	C	LPP	2.868	B				
	ADMM15	1.280	C							
	FT-100	1.008	C							
Benzo[b]Fluoranthene	DF-2	4.220	A	Pilot A	2.477	A	10	2.043	A	Pilot*Fuel Pilot*Mode Pilot*Fuel*Mode
	CA	2.557	B	Pilot B	1.867	B	11	1.503	B	
	ALS	1.188	C	LPP	0.9745	C				
	FT-100	0.4590	D							
	ADMM15	0.4403	D							
Benzo[k]Fluoranthene	DF-2	3.605	A	Pilot A	2.271	A	10	1.933	A	Pilot*Mode Pilot*Fuel*Mode
	CA	1.811	B	Pilot B	1.561	B	11	1.338	B	
	ALS	1.418	BC	LPP	1.074	C				
	ADMM15	0.8179	CD							
	FT-100	0.5250	D							

Table 26. Soluble Phase PAH Mass Emissions (µg/kWh) for Pilot Fuel Injection Study (contd)										
	Five Fuels, Three Pilot Conditions, Modes 10 and 11									
Response	**Fuel**	**LS Means[1]**	**Significant Fuel Groups[2]**	**Pilot Condition**	**LS Means[1]**	**Significant Pilot Groups[2]**	**Mode**	**LS Means[1]**	**Significant Mode Groups[2]**	**Significant Interactions**
Benzo[e]Pyrene	DF-2	2.576	A	Pilot A	1.715	A	10	1.414	A	Pilot*Fuel Pilot*Mode
	CA	1.736	B	Pilot B	1.336	B	11	1.029	B	
	ALS	0.8744	C	LPP	0.6136	C				
	ADMM15	0.5445	CD							
	FT-100	0.3756	D							
Benzo[a]Pyrene	DF-2	1.605	A	Pilot A	1.174	A	10	0.9299	A	Pilot*Fuel Pilot*Mode Fuel*Mode Pilot*Fuel*Mode
	CA	1.272	B	Pilot B	0.9329	B	11	0.6380	B	
	ALS	0.6400	C	LPP	0.2451	C				
	ADMM15	0.2424	D							
	FT-100	0.1609	D							
Indeno(1,2,3-cd)Pyrene	DF-2	1.139	A	Pilot A	0.6665	A	10	0.5068	NS	Pilot*Fuel Pilot*Mode Pilot*Fuel*Mode
	CA	0.5813	B	Pilot B	0.4817	B	11	0.4315		
	ADMM15	0.1084	C	LPP	0.2592	C				
	FT-100	0.0485	C							
Benzo[ghi]perylene	DF-2	1.718	A	Pilot A	1.072	A	10	0.8596	A	Pilot*Fuel Pilot*Mode Pilot*Fuel*Mode
	CA	1.054	B	Pilot B	0.8007	B	11	0.7248	B	
	ADMM15	0.2483	C	LPP	0.5038	C				
	FT-100	0.1488	C							

[1]Factor levels listed from highest to lowest least squares mean

[2]Letters designate groups of factor means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

Table 26 includes the pilot condition severity across fuels and modes for each soluble extract PAH compound. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average PAH compound emissions at each pilot condition. The general trend for pilot condition severity suggests LPP operation results in the lowest PAH emissions.

The mode severity across fuels and pilot condition for each toxin is also in Table 26. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average soluble PAH emissions at each mode. The general trend is mode 10 has significantly higher emissions than mode 11 across the fuels and pilot conditions. The Fuel*Pilot, Fuel*Mode, Pilot*Mode, and Fuel*Pilot*Mode interactions are indicated in Table 26 for each compound.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the pilot fuel injection study, and refer to the results in Table 26. The ANOVA tables for the pilot fuel injection evaluations can be found in Appendix F.

7.3.1 Naphthalene

Statistically significant differences exist in the average naphthalene among the fuels and modes. The average naphthalene response for the CA fuel is significantly different from the ADMM15, ALS and FT-100 fuels, Figure 67. There are not any statistically significant differences in the average naphthalene response across the pilot conditions, Figure 68.

The average naphthalene for modes 10 and 11 are significantly different from one another.

There is no significant interaction in the average naphthalene among the fuel and pilot condition, the mode and pilot condition, the mode and fuel combinations.

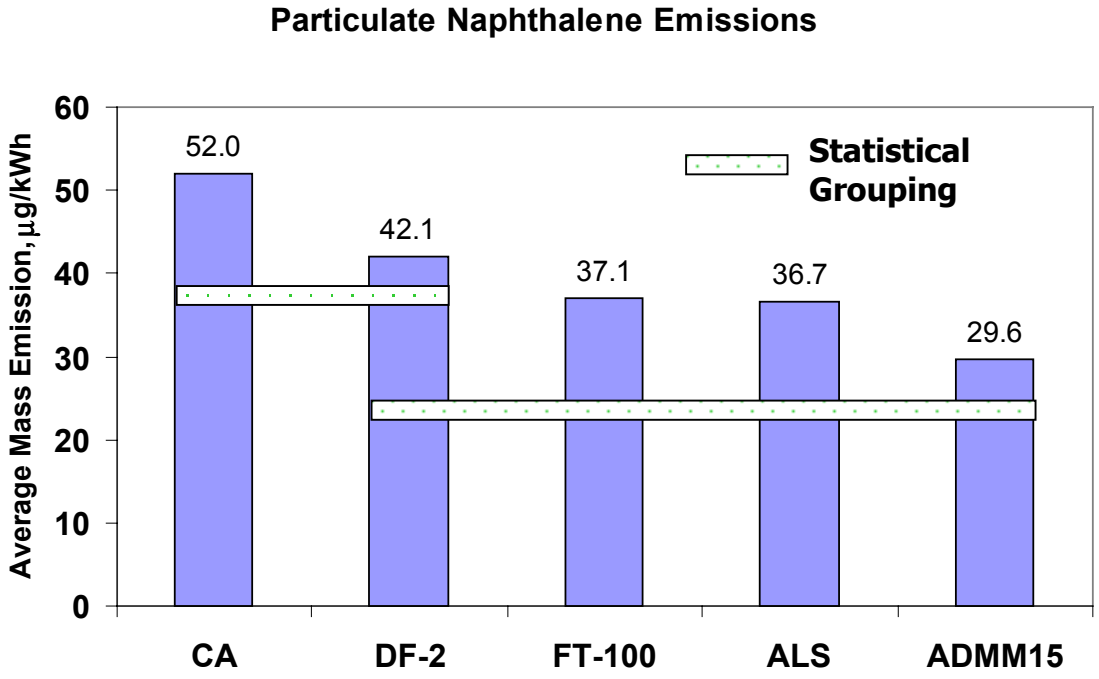


Figure 67. Test Fuel Average Particulate Phase Naphthalene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

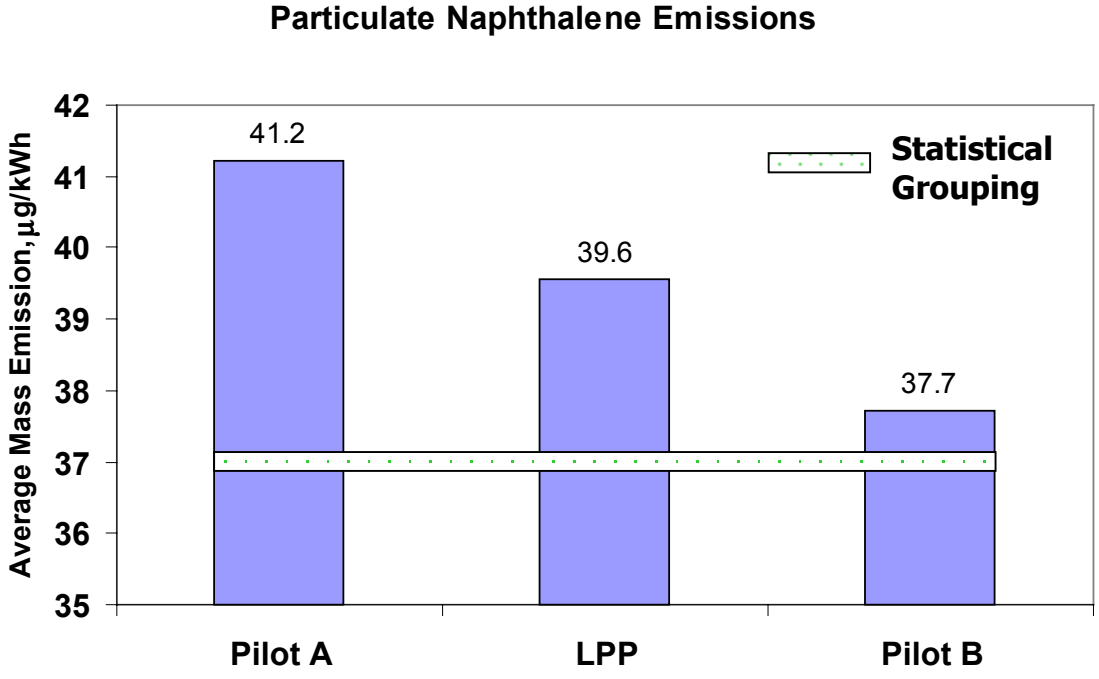


Figure 68. Pilot Condition Average Particulate Phase Naphthalene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.3.2 Acenaphthylene

Statistically significant differences exist in the average acenaphthylene among the pilot conditions, fuels, two-factor interactions, and the three-factor interaction fuel*mode*pilot condition. From Figure 69, the average acenaphthylene for the ADMM15 fuel is significantly different from the FT-100 fuel. The CA, DF-2, and ALS fuels are not significantly different from either the ADMM15 or the FT-100 fuels with respect to the average acenaphthylene.

The average acenaphthylene for the LPP and Pilot A conditions are not significantly different from one another, but are significantly different from the Pilot B condition as seen in Figure 70.

The average acenaphthylene for modes 10 and 11 are not significantly different from one another.

The trend in the average acenaphthylene across the pilot conditions for the FT-100 fuel is significantly different than the trends for the remaining four fuels. The average acenaphthylene for the FT-100 fuel at the Pilot B condition is significantly different than the other four fuels, but not at the LPP or the Pilot A condition.

The average acenaphthylene at the Pilot B condition for Mode 11 is significantly different than Mode 10. There is not any significant difference in the average acenaphthylene between the two modes at the LPP or Pilot A conditions.

The trend in the average acenaphthylene across the two modes is different at the FT-100 fuel. There does not appear to be differences in the average acenaphthylene for the two modes at the ADMM15, ALS, CA, or DF-2 fuels.

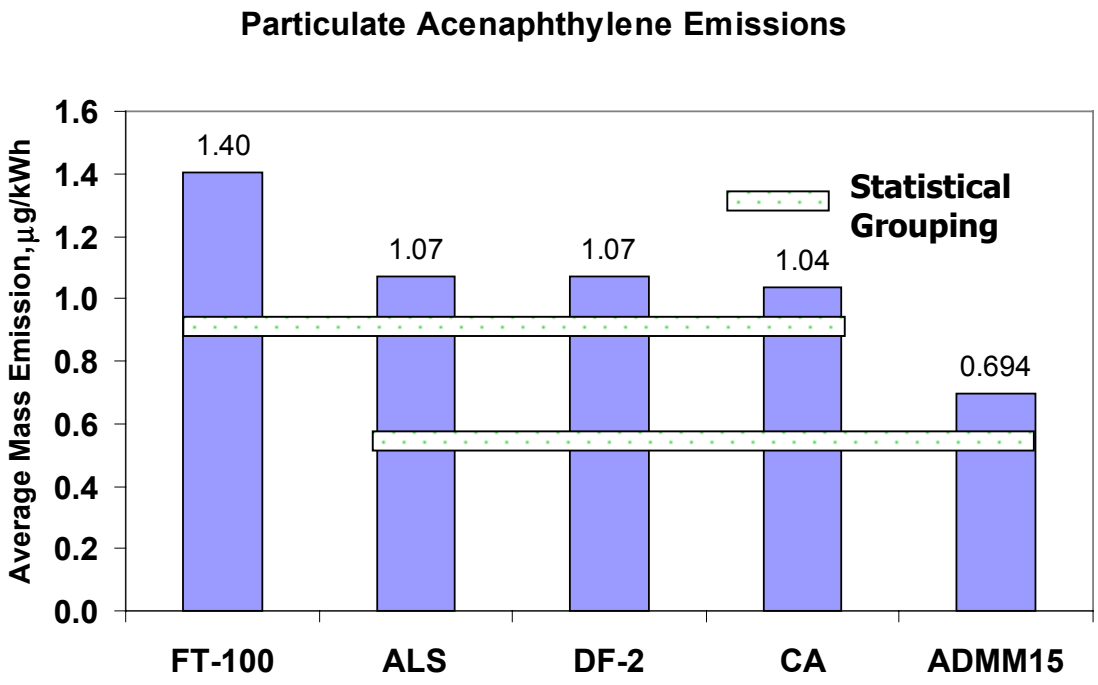


Figure 69. Test Fuel Average Particulate Phase Acenaphthylene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

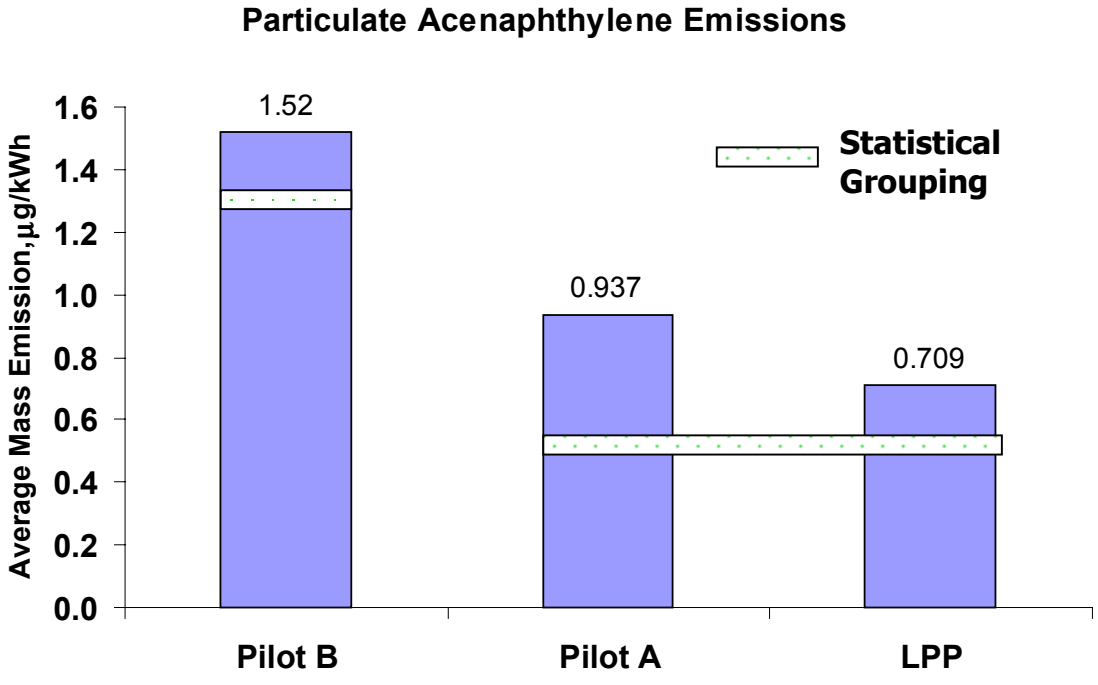


Figure 70. Pilot Condition Average Particulate Phase Acenaphthylene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.3.3 Acenaphthene

Statistically significant differences were apparent in the average acenaphthene among the pilot conditions, fuels, modes, and pilot condition*fuel interaction. The average acenaphthene for the CA fuel is significantly different from the ADMM15 and the FT-100 fuels. Figure 71 shows the acenaphthene response for the test fuels averaged across the pilot conditions and modes.

The average acenaphthene responses for the pilot conditions are shown in Figure 72. The average acenaphthene for the LPP condition is significantly different than the Pilot A condition. The average acenaphthene for the Pilot B condition is not significantly different from with either the LPP or the Pilot A conditions.

The average acenaphthene for modes 10 and 11 are significantly different from one another.

The trends in the average acenaphthene for the ALS and CA fuels are significantly different than the DF-2 fuel between the LPP and Pilot A conditions.

There is no significant interaction in the average acenaphthene among the pilot condition and mode combinations.

There is no significant interaction in the average acenaphthene among the fuel and mode combinations.

7.3.4 Fluorene

Statistically significant differences were noted in the average fluorene among the fuels, modes, and pilot condition*fuel interaction. The average fluorene for the ALS, CA, and DF-2 fuels are significantly different from the FT-100 fuel, but not significantly different from one another. Also, the average fluorene for the ALS fuel is significantly different from the ADMM15 fuel. The fluorene response for the test fuels is shown in Figure 73.

Figure 74 reveals that there were no significant differences in the average fluorene among the pilot conditions.

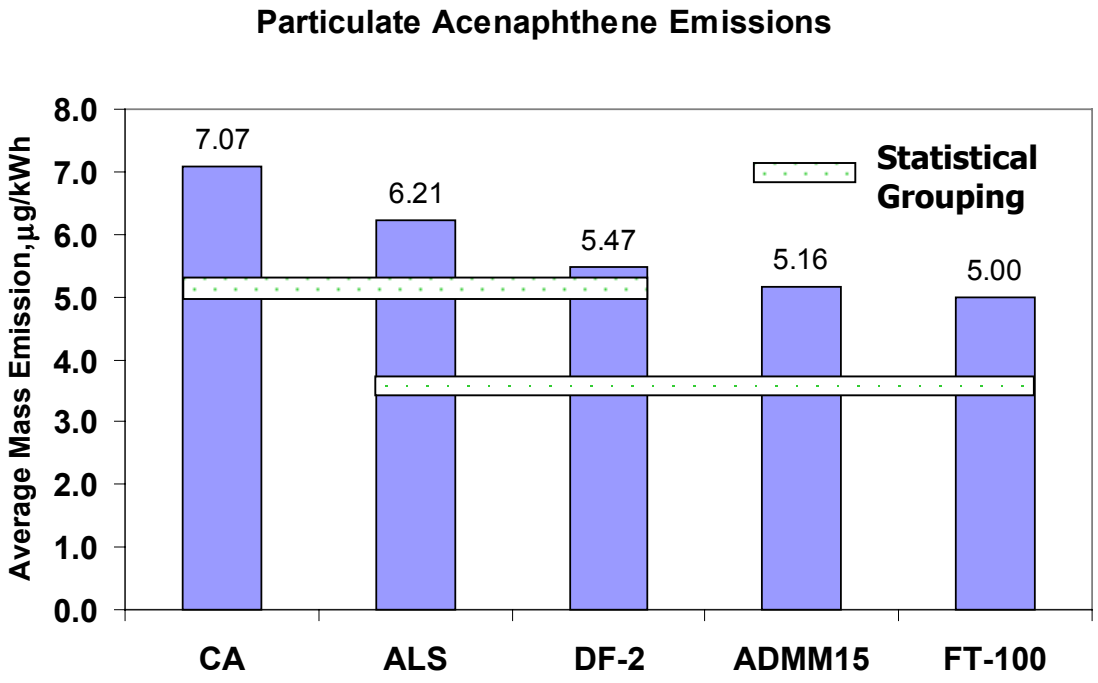


Figure 71. Test Fuel Average Particulate Phase Acenaphthene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

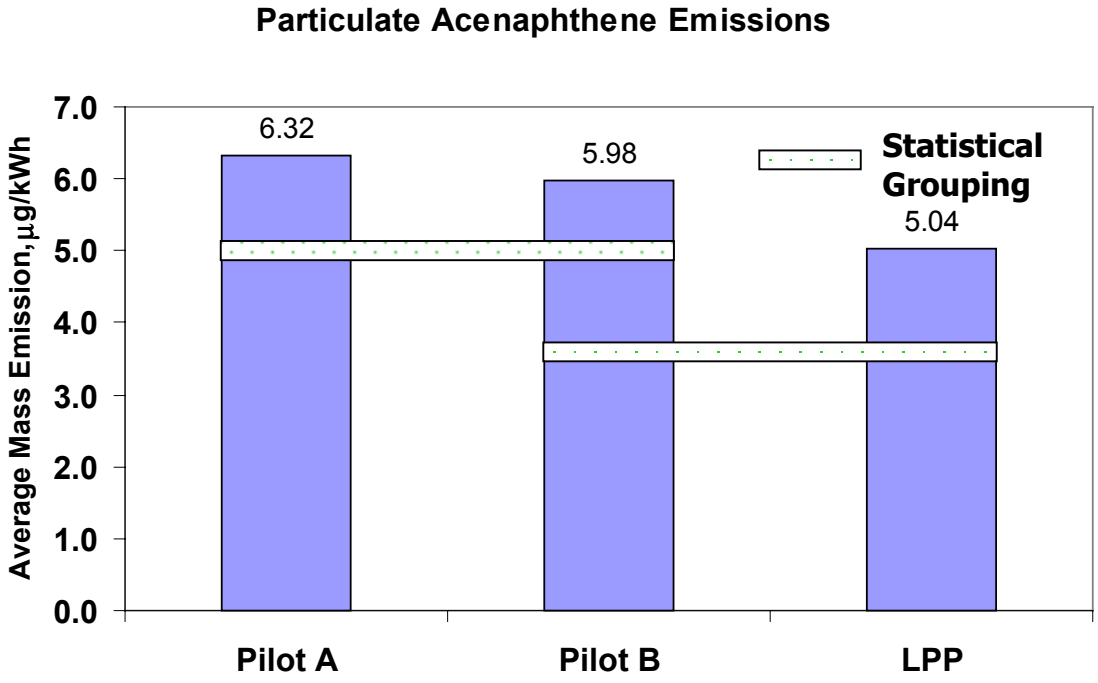


Figure 72. Pilot Condition Average Particulate Phase Acenaphthene Mass Emissions for Test Fuels and Modes (µg/kWh)

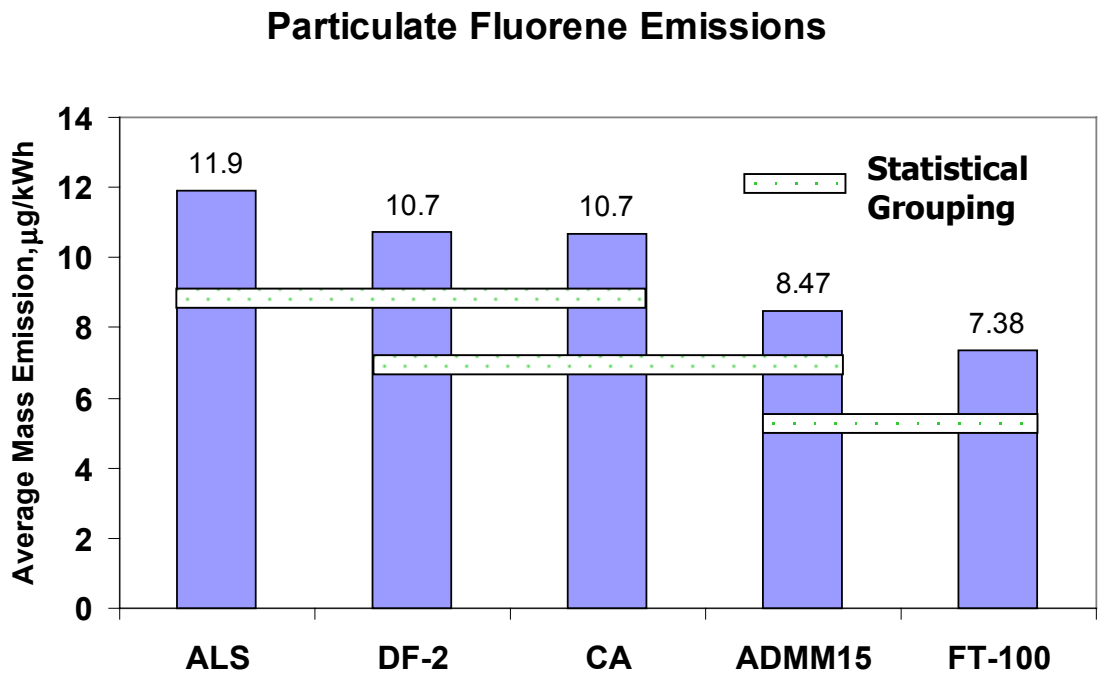


Figure 73. Test Fuel Average Particulate Phase Fluorene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

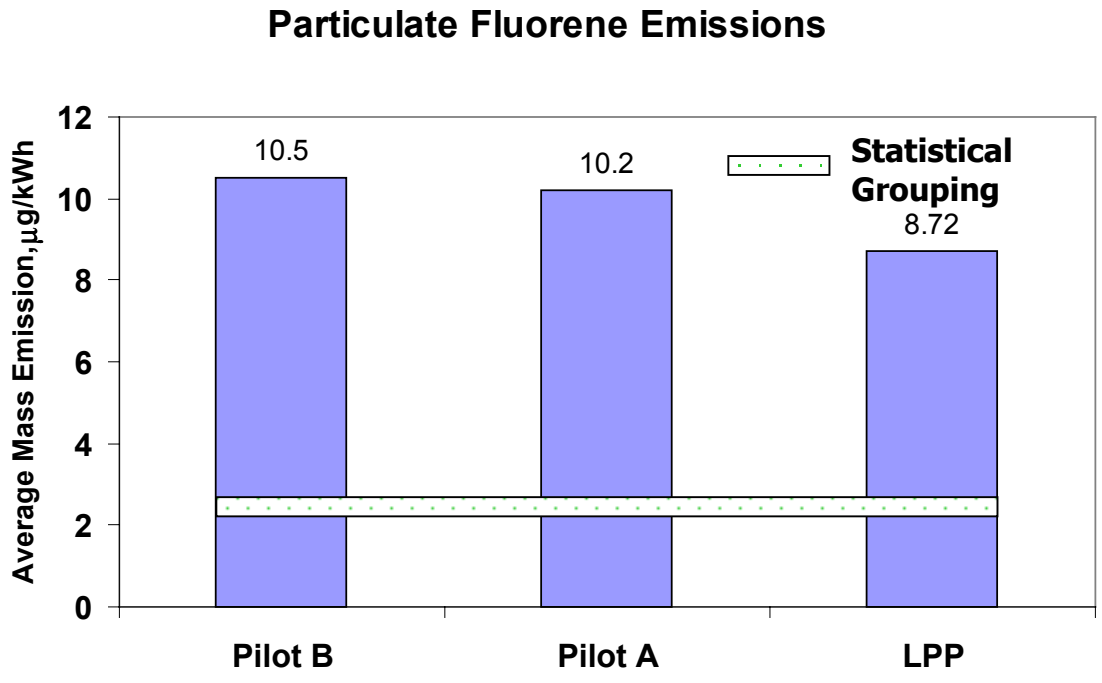


Figure 74. Pilot Condition Average Particulate Phase Fluorene Mass Emissions for Test Fuels and Modes (µg/kWh)

The average fluorene for modes 10 and 11 are significantly different from one another,

The trend in the average fluorene for the DF-2 fuel is significantly different than the ALS fuel between the LPP and Pilot A conditions. The CA, ADMM15, and FT-100 fuels demonstrate similar trends across the pilot conditions with respect to the average fluorene.

There is no significant interaction in the average fluorene among the pilot condition and mode combinations.

There is no significant interaction in the average fluorene among the fuel and mode combinations.

7.3.5 Phenanthrene

Statistically significant differences exist in the average phenanthrene among the pilot conditions, fuels, and pilot condition*fuel interaction. The average phenanthrene for the DF-2 fuel is significantly different than the remaining four fuels as shown in Figure 75. The average phenanthrene for the ADMM15, FT-100, Ca, and ALS fuels are not significantly different from one another.

The average phenanthrene, Figure 76, for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.

There is no significant difference in the average phenanthrene among the two modes.

The trend in the average phenanthrene across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average phenanthrene for the DF-2 fuel at the Pilot A and Pilot B conditions are significantly different than the other four fuels.

There is no significant interaction in the average phenanthrene among the pilot condition and mode combinations.

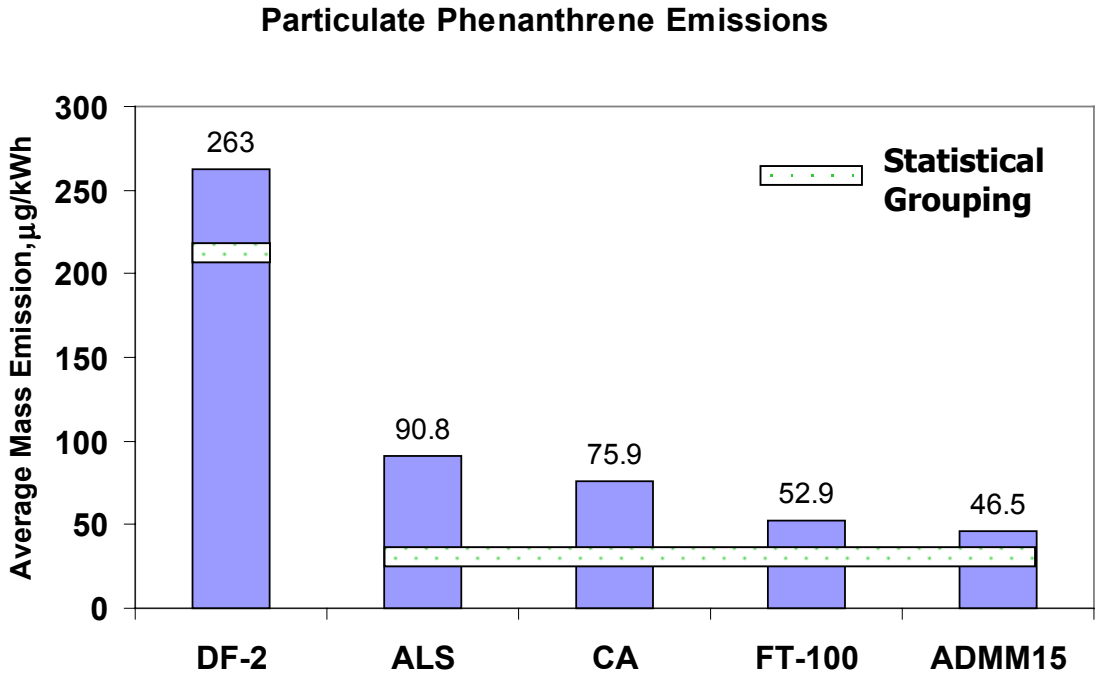


Figure 75. Test Fuel Average Particulate Phase Phenanthrene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

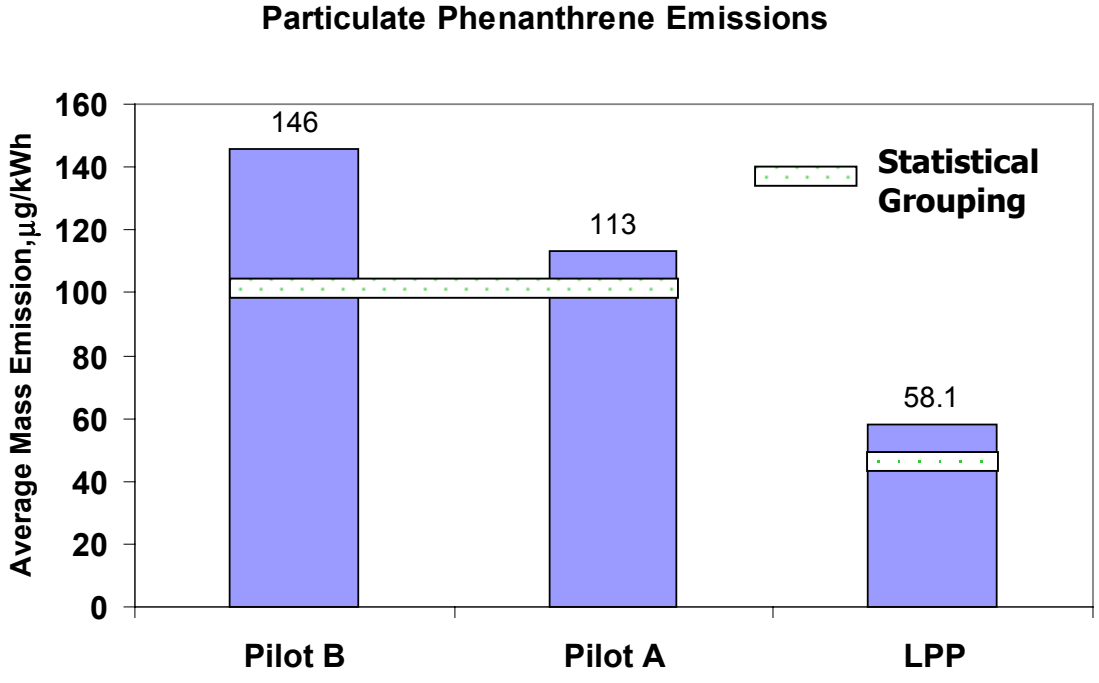


Figure 76. Pilot Condition Average Particulate Phase Phenanthrene Mass Emissions for Test Fuels and Modes (µg/kWh)

There is no significant interaction in the average phenanthrene among the fuel and mode combinations.

7.3.6 Anthracene

Statistically significant differences were noted in the average anthracene among the pilot conditions, fuels, pilot condition*fuel interaction, fuel*mode interaction, and the three-factor interaction. Figure 77 reveals there are three distinct fuel groupings with respect to the average anthracene. The average anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The ADMM15 and FT-100 fuels are not significantly different from one another, but are significantly different than the remaining three fuels. Also, the CA and ALS fuels are not significantly different from one another, but are significantly different from the remaining fuels.

The average anthracene for the LPP and Pilot A conditions are not significantly different from one another, but are significantly different from the Pilot B condition as seen in Figure 78.

There is no significant difference in the average anthracene among the two modes.

The trends in the average anthracene across the pilot conditions for the DF-2 and ALS fuels are significantly different than the trends for the remaining three fuels. The average anthracene for the DF-2 fuel at the Pilot A and Pilot B conditions are significantly different than the CA, FT-100, and ADMM15 fuels.

There is no significant interaction in the average anthracene among the pilot condition and mode combinations.

The trends in the average anthracene for modes 10 and 11 are significantly different at the CA fuel. Otherwise, the average anthracene for the two modes are not significantly different across the remaining four fuels.

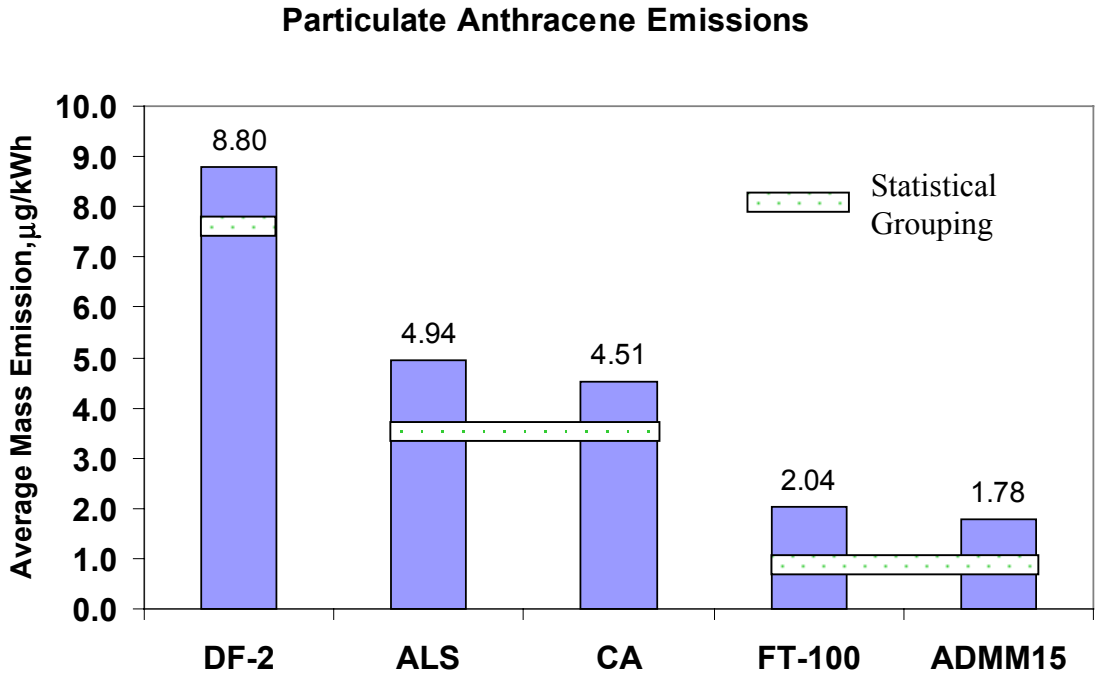


Figure 77. Test Fuel Average Particulate Phase Anthracene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

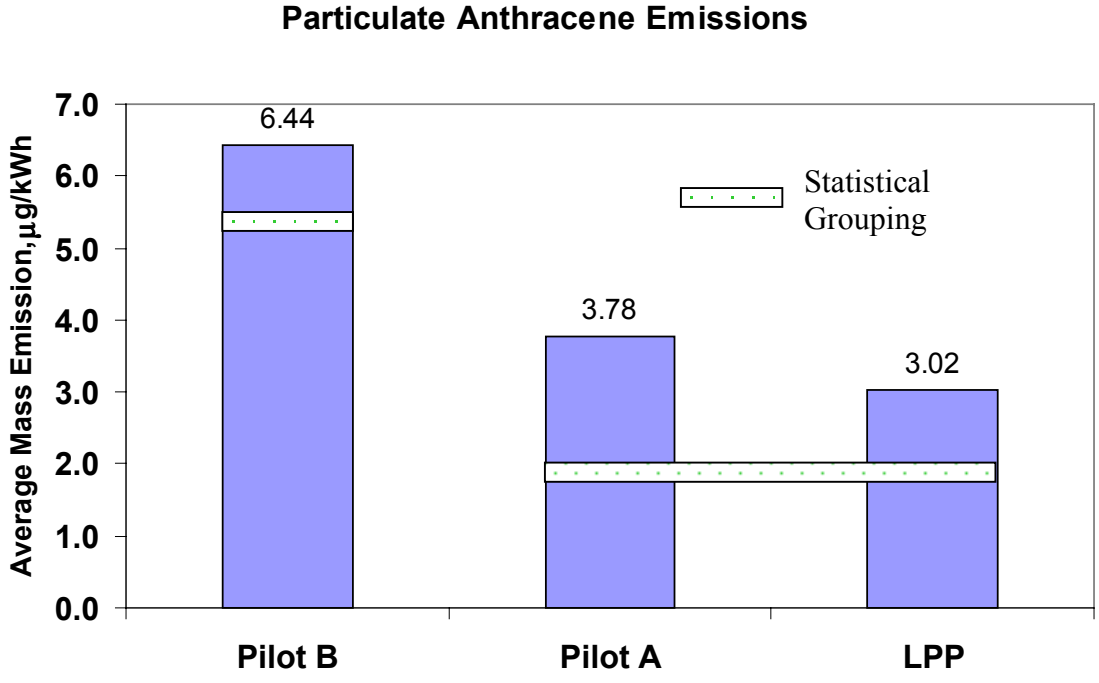


Figure 78. Pilot Condition Average Particulate Phase Anthracene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.3.7 Fluoranthene

Statistically significant differences were apparent in the average fluoranthene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, and fuel*mode interaction. There are three distinct fuel groupings with respect to the average fluoranthene shown in Figure 79. The average fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The ADMM15 and FT-100 fuels are not significantly different from one another, but are significantly different than the remaining three fuels. Also, the CA and ALS fuels are not significantly different from one another, but are significantly different from the remaining fuels.

The average fluoranthene for the Pilot A and Pilot B conditions are not significantly different from one another, Figure 80, but are significantly different from the LPP condition.

The average fluoranthene for modes 10 and 11 are significantly different from one another.

The trend in the average fluoranthene across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average fluoranthene for the DF-2 fuel at the LPP condition is significantly different than the other four fuels.

There is no significant interaction in the average fluoranthene among the pilot condition and mode combinations.

The trends in the average fluoranthene for modes 10 and 11 are significantly different at the CA fuel. Otherwise, the average fluoranthene for the two modes are not significantly different across the remaining four fuels.

7.3.8 Pyrene

Statistically significant differences exist in the average pyrene among the pilot conditions, fuels, modes, and pilot condition*fuel interaction. From Figure 81, it is seen that there are several distinct fuel groupings with respect to the average pyrene. The average pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The FT-100 fuel is significantly different than the ALS and CA fuels, but not significantly different than the ADMM15 fuel. The average pyrene for modes 10 and 11 are significantly different from one another.

The average pyrene, shown in Figure 82, for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.

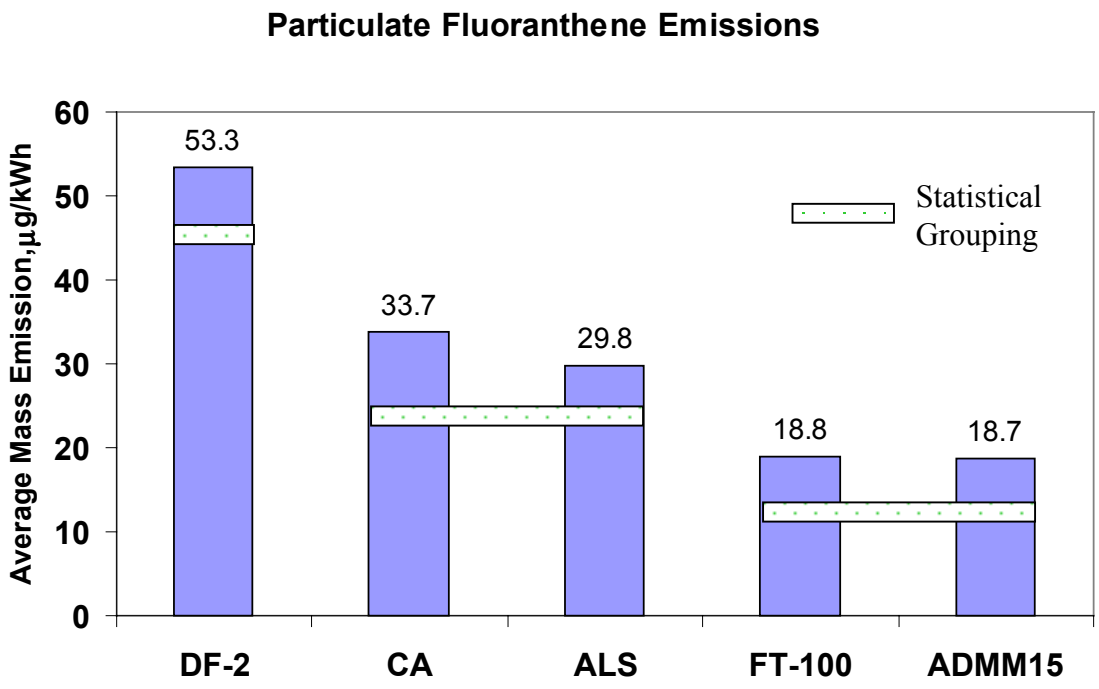


Figure 79. Test Fuel Average Particulate Phase Fluoranthene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

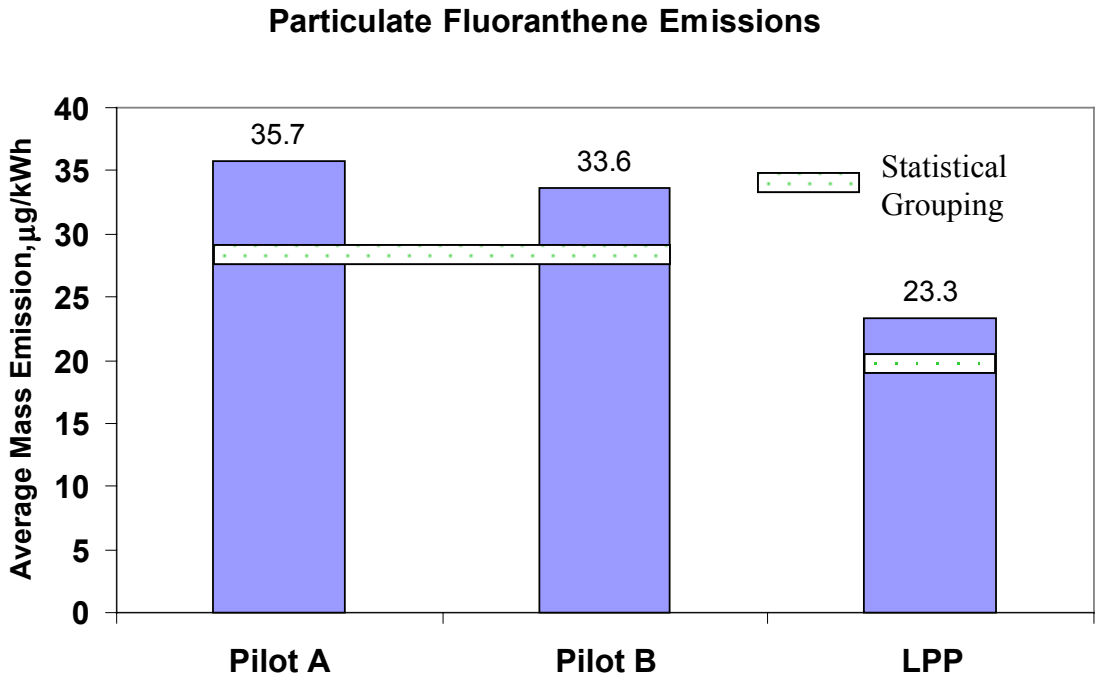


Figure 80. Pilot Condition Average Particulate Phase Fluoranthene Mass Emissions for Test Fuels and Modes (µg/kWh)

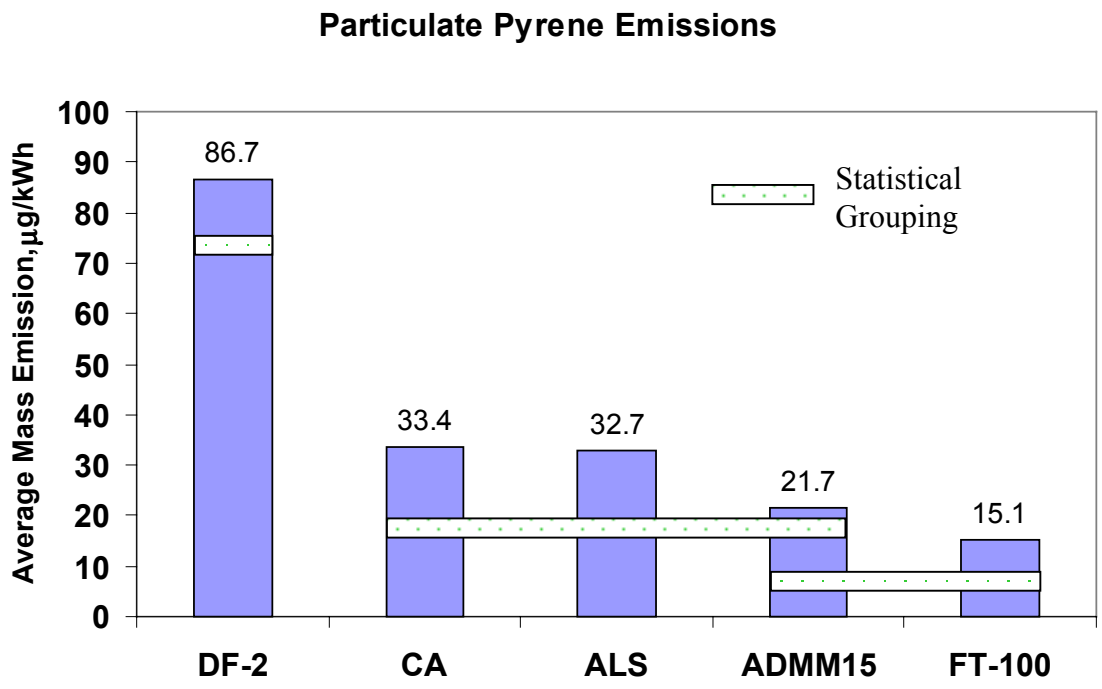


Figure 81. Test Fuel Average Particulate Phase Pyrene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

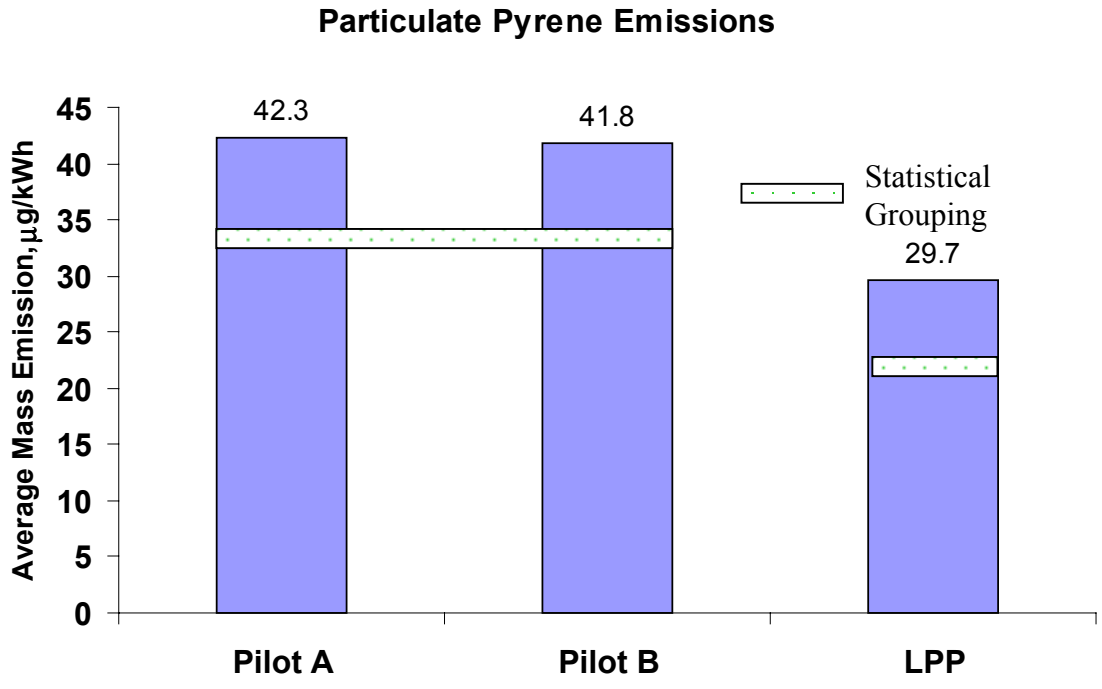


Figure 82. Pilot Condition Average Particulate Phase Pyrene Mass Emissions for Test Fuels and Modes (µg/kWh)

The trend in the average pyrene across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels.

There is no significant interaction in the average pyrene among the pilot condition and mode combinations.

There is no significant interaction in the average pyrene among the fuel and mode combinations.

7.3.9 Benzo[a]anthracene

Statistically significant differences exist in the average benzo[a]anthracene among the pilot conditions, fuels, modes, and pilot condition*mode interaction. Figure 83 shows three distinct fuel groupings with respect to the average benzo[a]anthracene. Fuels DF-2 and CA are significantly different from one another and the remaining three fuels. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly different than the other two fuels.

The average benzo[a]anthracene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition as seen in Figure 84.

The average benzo[a]anthracene for mode 10 is significantly different than mode 11.

The trends in the average benzo[a]anthracene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average benzo[a]anthracene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, ALS, and FT-100 fuels.

There is no significant interaction in the average benzo[a]anthracene among the pilot condition and mode combinations.

There is no significant interaction in the average benzo[a]anthracene among the fuel and mode combinations.

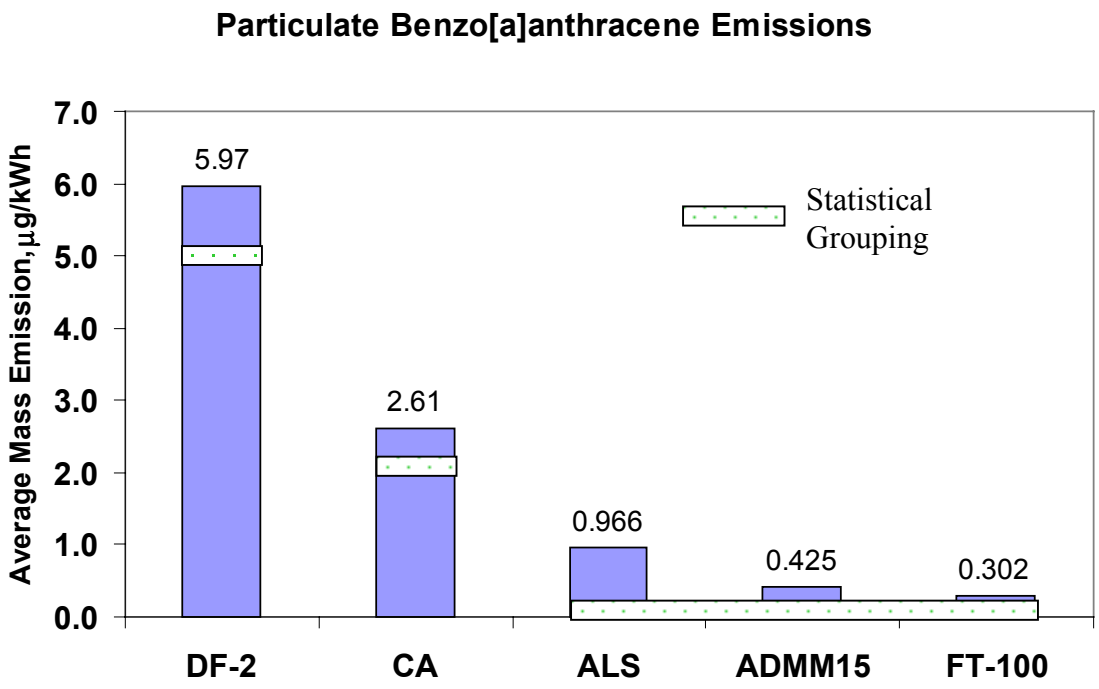


Figure 83. Test Fuel Average Particulate Phase Benzo[a]anthracene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

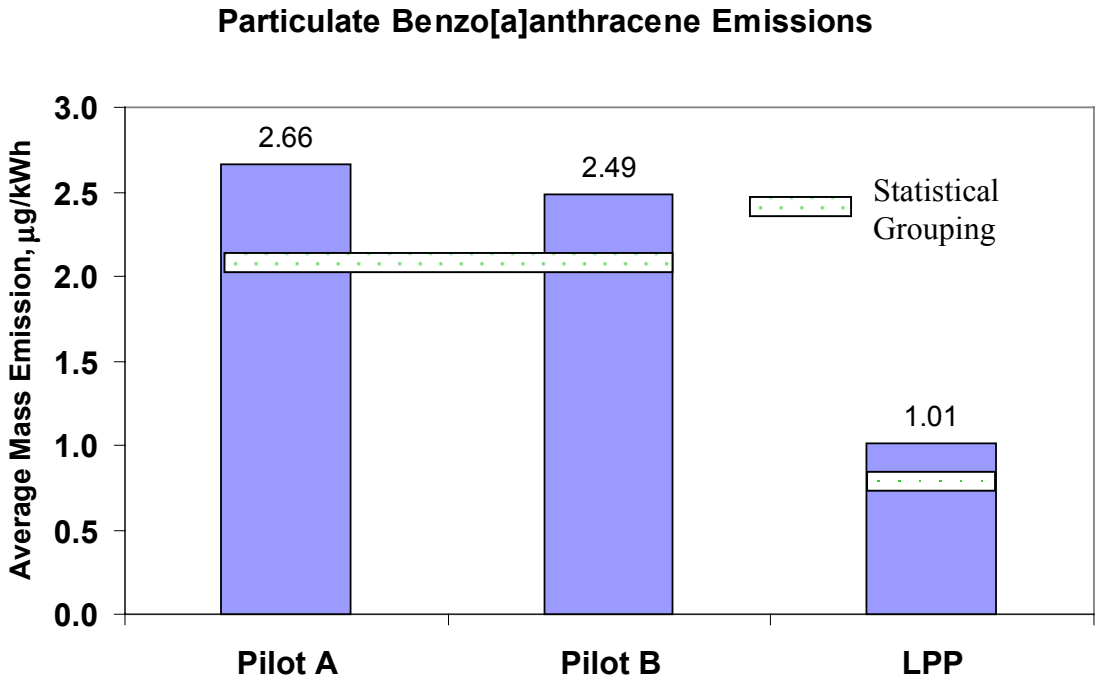


Figure 84. Pilot Condition Average Particulate Phase Benzo[a]anthracene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.3.10 Chrysene

Statistically significant differences were apparent in the average chrysene among the pilot conditions, fuels, modes, and pilot condition*fuel interaction. There are three distinct fuel groupings with respect to the average chrysene in Figure 85. Fuels DF-2 and CA are significantly different from one another and the remaining three fuels. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly different than the other two fuels.

The particulate bound PAH Chrysene emissions in Figure 86 show the two pilot operation conditions to be different from LPP operation..

The average chrysene for mode 10 is significantly different than mode 11.

The trends in the average chrysene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average chrysene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.

There is no significant interaction in the average chrysene among the pilot condition and mode combinations, or among the fuel and mode combinations.

7.3.11 Benzo[b]fluoranthene

Statistically significant differences were noted in the average benzo[b]fluoranthene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, pilot condition*mode interaction, and the three-factor interaction. The average benzo[b]fluoranthene for the ALS, CA, and DF-2 fuels are significantly different from one another and the remaining two fuels, Figure 87. The average benzo[b]fluoranthene for the ADMM15 and FT-100 fuels are not significantly different from one another.

The average benzo[b]fluoranthene for the three pilot conditions are all significantly different from one another, Figure 88.

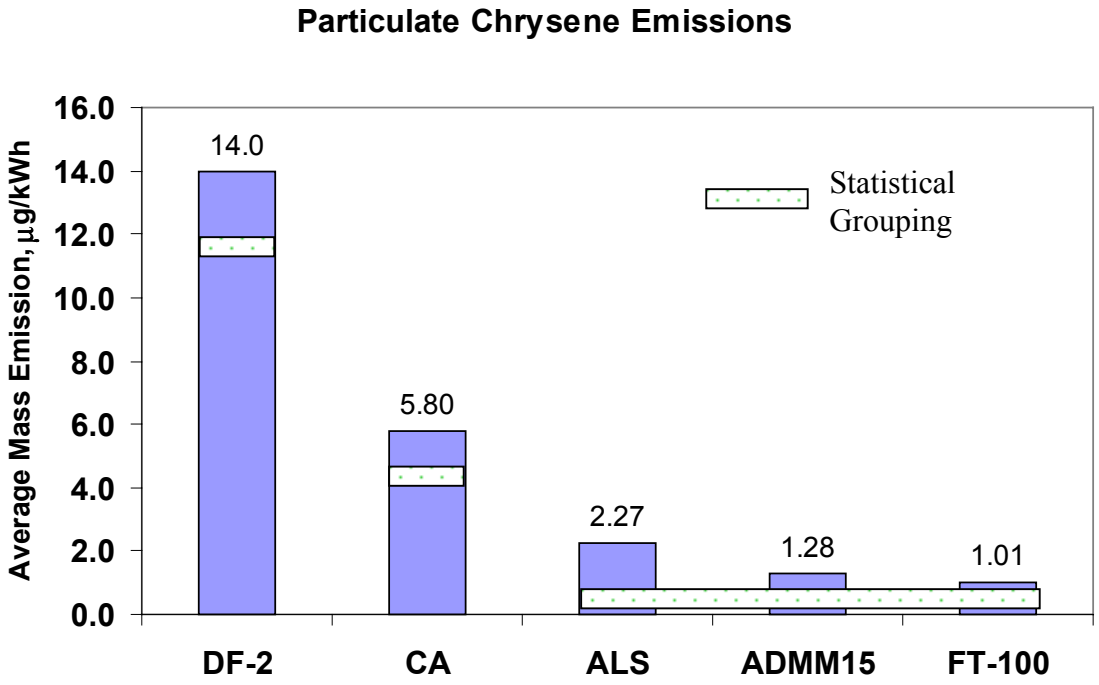


Figure 85. Test Fuel Average Particulate Phase Chrysene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

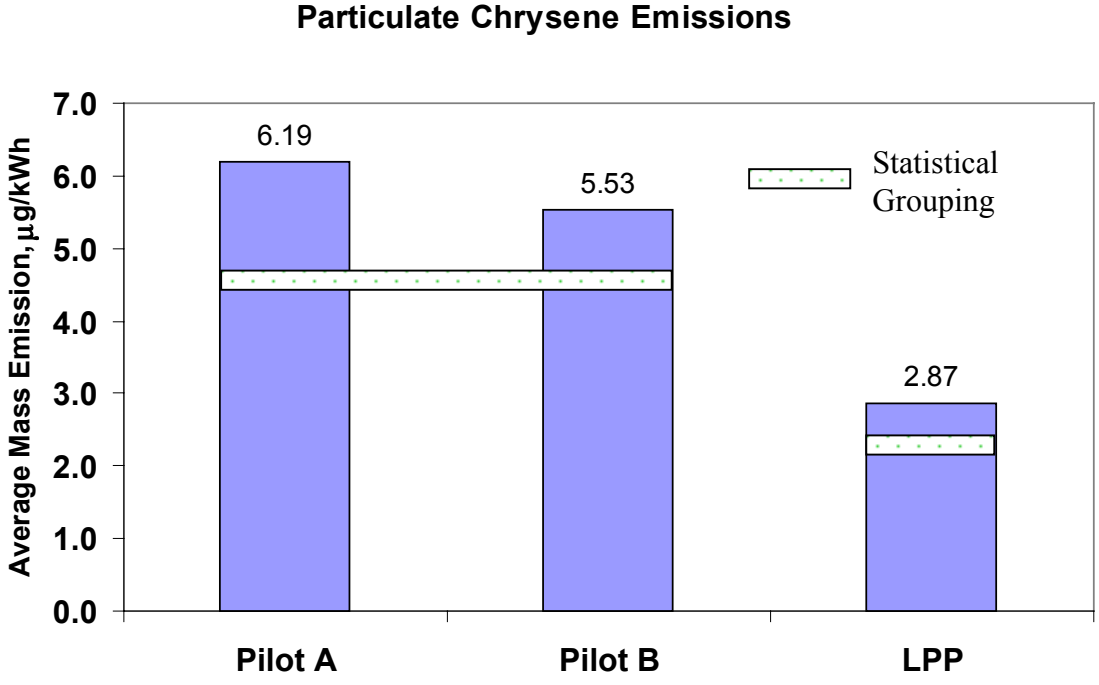


Figure 86. Pilot Condition Average Particulate Phase Chrysene Mass Emissions for Test Fuels and Modes (µg/kWh)

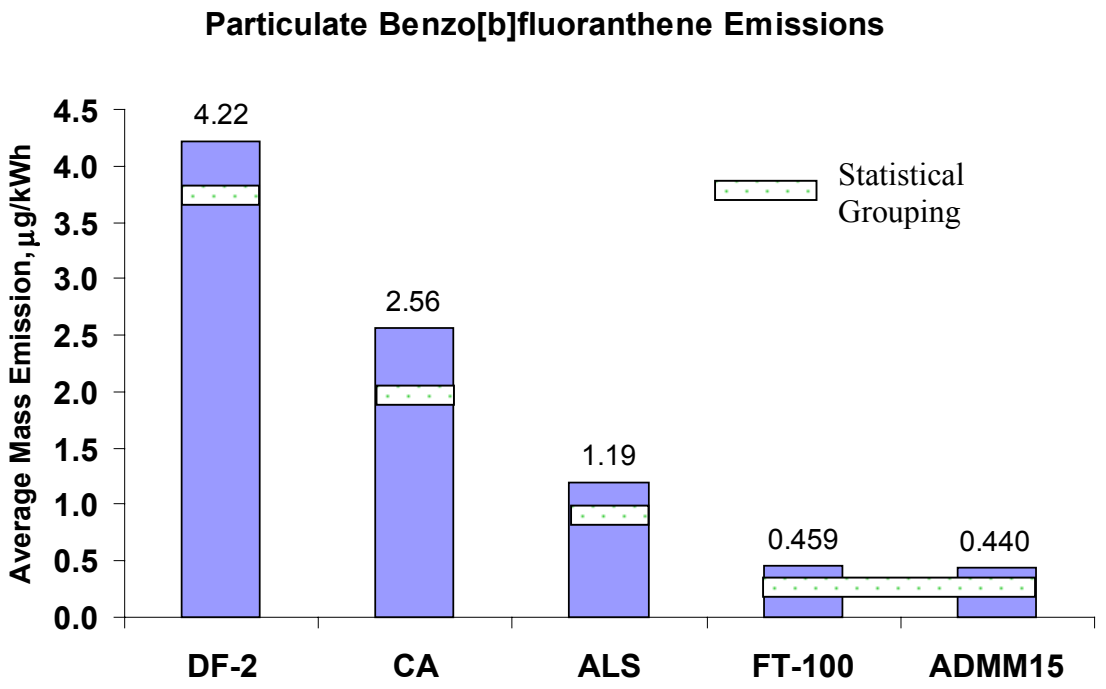


Figure 87 Test Fuel Average Particulate Phase Benzo[b]fluoranthene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

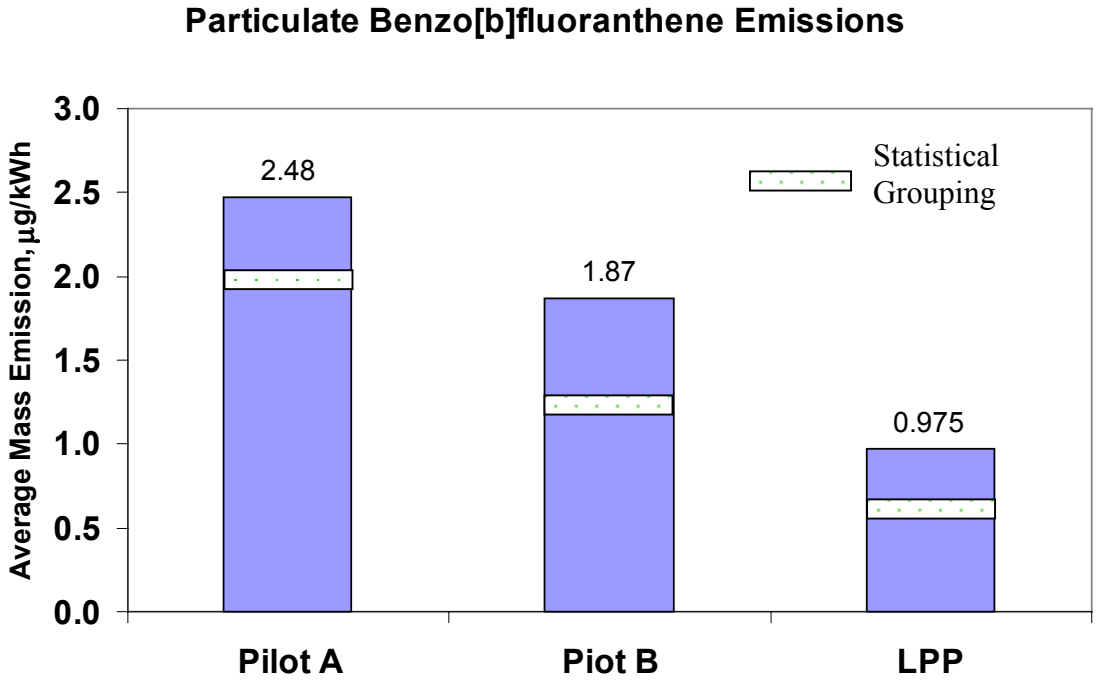


Figure 88. Pilot Condition Average Particulate Phase Benzo[b]fluoranthene Mass Emissions for Test Fuels and Modes (µg/kWh)

The average benzo[b]fluoranthene for modes 10 and 11 are significantly different from one another.

The trends in the average benzo[b]fluoranthene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average benzo[b]fluoranthene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.

The average benzo[b]fluoranthene at the Pilot A condition for Mode 10 is significantly different than Mode 11. There is not any significant difference in the average benzo[b]fluoranthene between the two modes at the LPP or Pilot B conditions.

There is no significant interaction in the average benzo[b]fluoranthene among the fuel and mode combinations.

7.3.12 Benzo[k]fluoranthene

Statistically significant differences exist in the average benzo[b]fluoranthene among the pilot conditions, fuels, modes, pilot condition*mode interaction, and the three-factor interaction. There are several distinct fuel groupings with respect to the average benzo[k]fluoranthene shown in Figure 89. The DF-2 fuel is significantly different from the remaining four fuels. The CA fuel is significantly different than the ADMM15 and the FT-100 fuels, but not significantly different than the ALS fuel. Also, the ALS fuel is significantly different than the FT-100 fuel.

In Figure 90, the average benzo[f]fluoranthene for the three pilot conditions are shown to be significantly different from one another.

The average benzo[k]fluoranthene for mode 10 is significantly different than mode 11.

There is no significant interaction in the average benzo[k]fluoranthene among the fuel and pilot condition combinations.

The average benzo[k]fluoranthene at the Pilot A condition for Mode 10 is significantly different than Mode 11. There is not any significant difference in the average benzo[k]fluoranthene between the two modes at the LPP or Pilot B conditions.

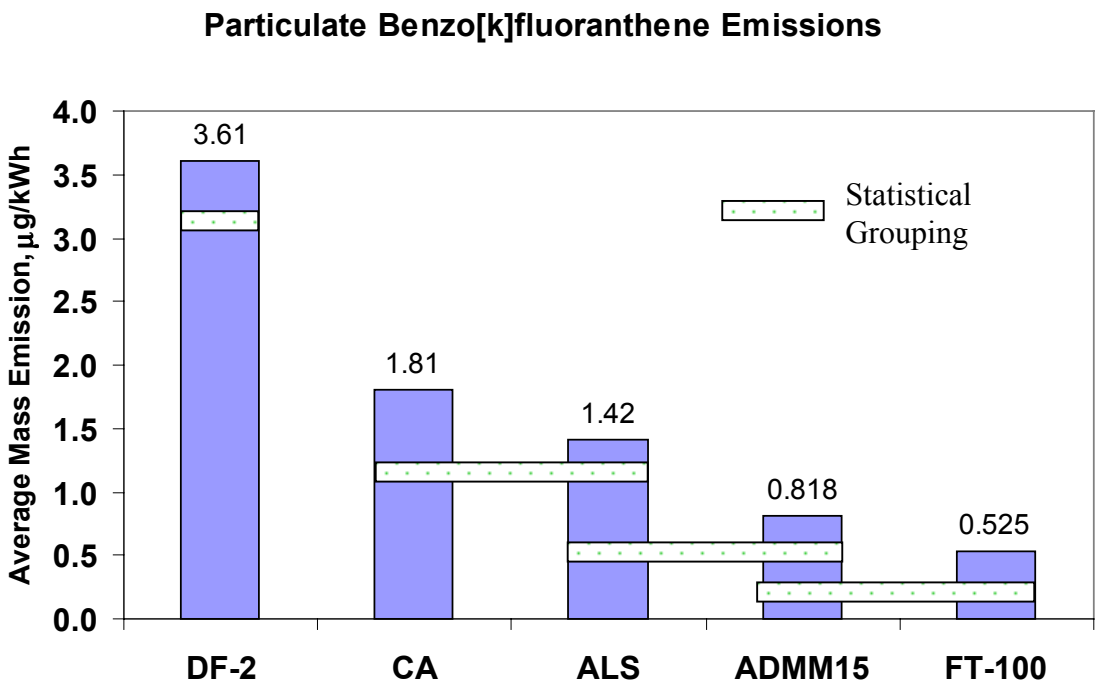


Figure 89. Test Fuel Average Particulate Phase Benzo[k]fluoranthene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

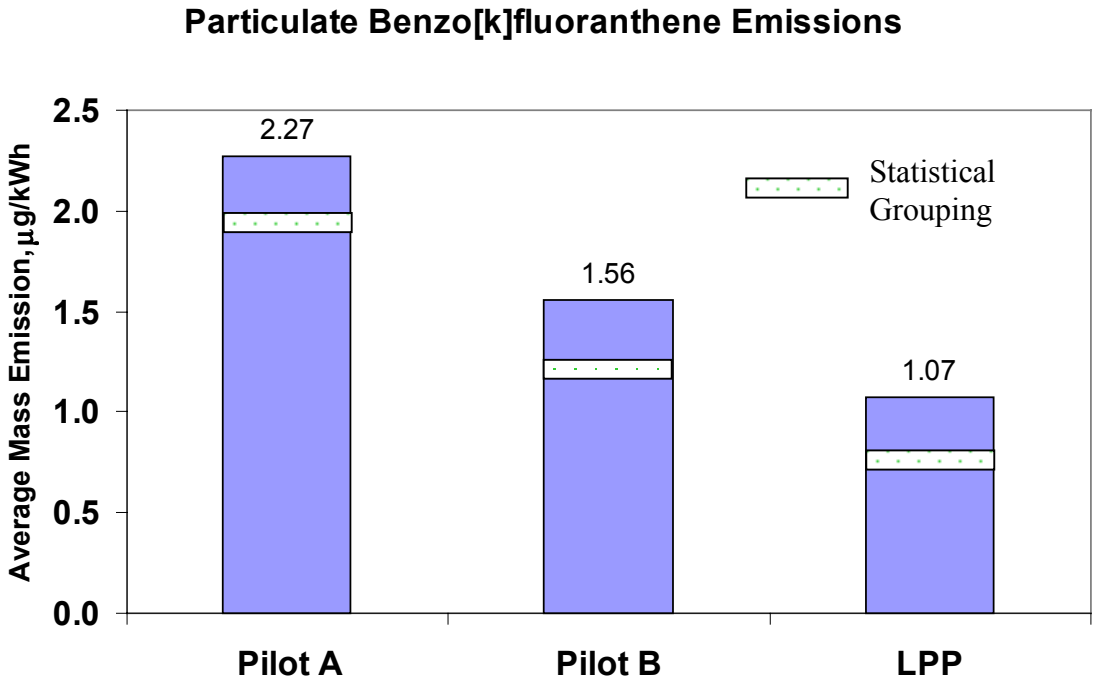


Figure 90. Pilot Condition Average Particulate Phase Benzo[k]fluoranthene Mass Emissions for Test Fuels and Modes (µg/kWh)

There is no significant interaction in the average benzo[k]fluoranthene among the fuel and mode combinations.

7.3.13 Benzo[e]pyrene

Statistically significant differences were noted in the average benzo[e]pyrene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, and pilot condition*mode interaction. There are several distinct fuel groupings with respect to the average benzo[e]pyrene. The DF-2 and CA fuels are significantly different from the remaining three fuels. Also, the ALS fuel is significantly different than the FT-100 fuel, Figure 91.

The average benzo[e]pyrene for the three pilot conditions are significantly different from one another, Figure 92.

The average benzo[e]pyrene for mode 10 is significantly different than mode 11.

The trends in the average benzo[e]pyrene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average benzo[e]pyrene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.

The average benzo[e]pyrene at the Pilot A condition for Mode 10 is significantly different than Mode 11. There is not any significant difference in the average benzo[e]pyrene between the two modes at the LPP or Pilot B conditions.

There is no significant interaction in the average benzo[e]pyrene among the fuel and mode combinations.

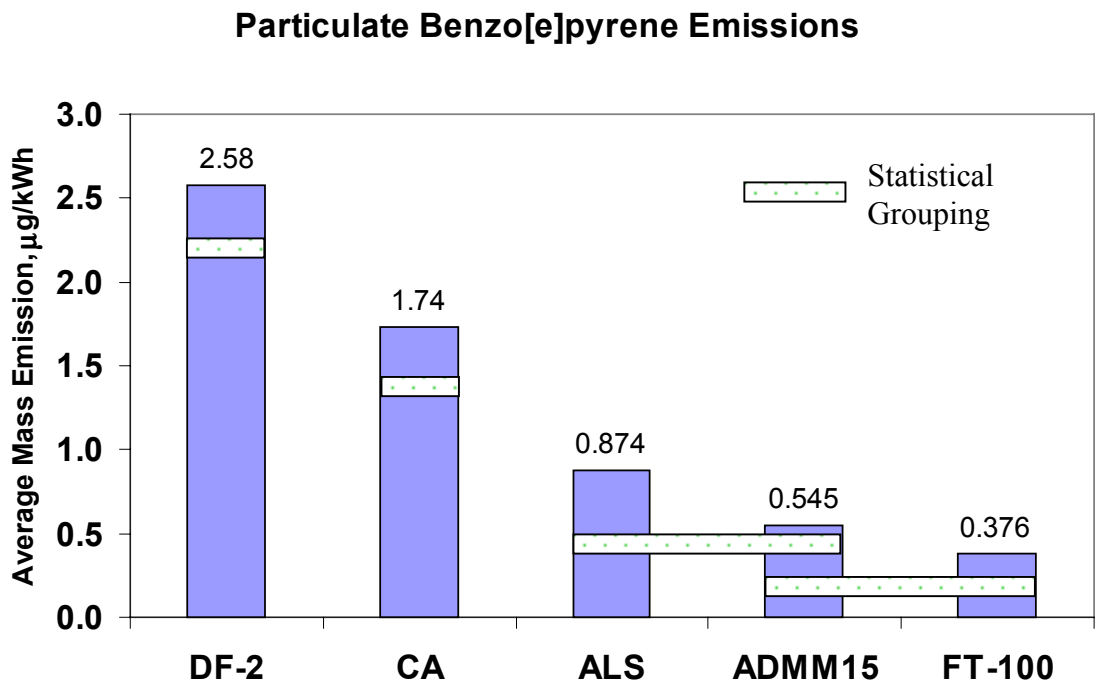


Figure 91. Test Fuel Average Particulate Phase Benzo[e]pyrene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

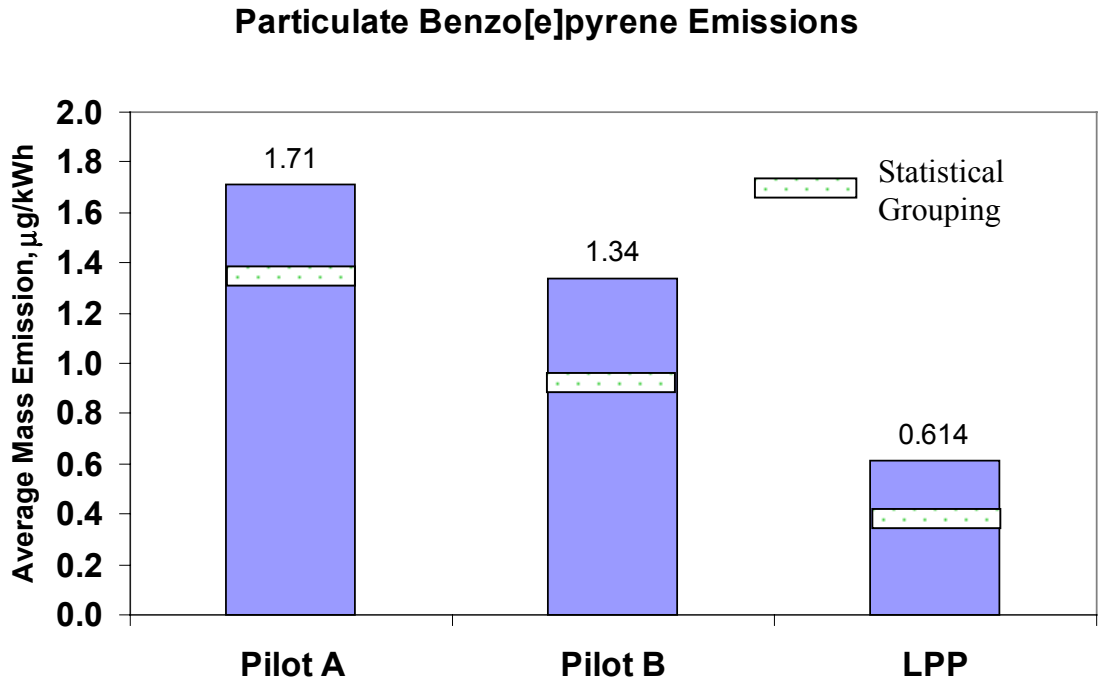


Figure 92. Pilot Condition Average Particulate Phase Benzo[e]pyrene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.3.14 Benzo[a]pyrene

Statistically significant differences were noted in the average benzo[a]pyrene among the pilot conditions, fuels, modes, two-factor interactions, and the three-factor interaction fuel*mode*pilot condition. Figure 93 shows the average benzo[a]pyrene for the DF-2, CA, and ALS fuels to be significantly different from one another and the remaining two fuels. The average benzo[a]pyrene for the ADMM15 and FT-100 fuels are not significantly different from one another.

From Figure 94 the average benzo[a]pyrene for the three pilot conditions is seen to be significantly different from each another.

The average benzo[a]pyrene for mode 10 is significantly different than mode 11.

The trends in the average benzo[a]pyrene across the pilot conditions for the CA and DF-2 fuels are significantly different than the trends for the remaining three fuels. The average benzo[a]pyrene for the CA and DF-2 fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.

The average benzo[a]pyrene at the Pilot A condition for mode 10 is significantly different than mode 11. There is not any significant difference in the average benzo[a]pyrene between the two modes at the LPP or Pilot B conditions.

The average benzo[a]pyrene for the CA and DF-2 fuels for mode 10 is significantly different than mode 11. There is not any significant difference in the average benzo[a]pyrene between the modes for the ADMM15, ALS, or FT-100 fuels.

7.3.15 Indeno(1,2,3-cd)pyrene

For the PAH indeno(1,2,3-cd)pyrene, sufficient interference in the chromatograms from the ALS fuel extracts for the pilot conditions existed that there were numerous non-detects with the low-resolution mass spectrometer. The high-resolution instrument was only used on those extracts when the LPP control condition was utilized AND that did not have a benzo[a]pyrene response. The ALS fuel at the LPP control condition had low-resolution response for benzo[a]pyrene, but non-detects for indeno(1,2,3-cd)pyrene. There were also numerous non-detects at the conditions with pilot fuel injection enabled. Thus ALS was not included in the ANOVA for indeno(1,2,3-cd)pyrene.

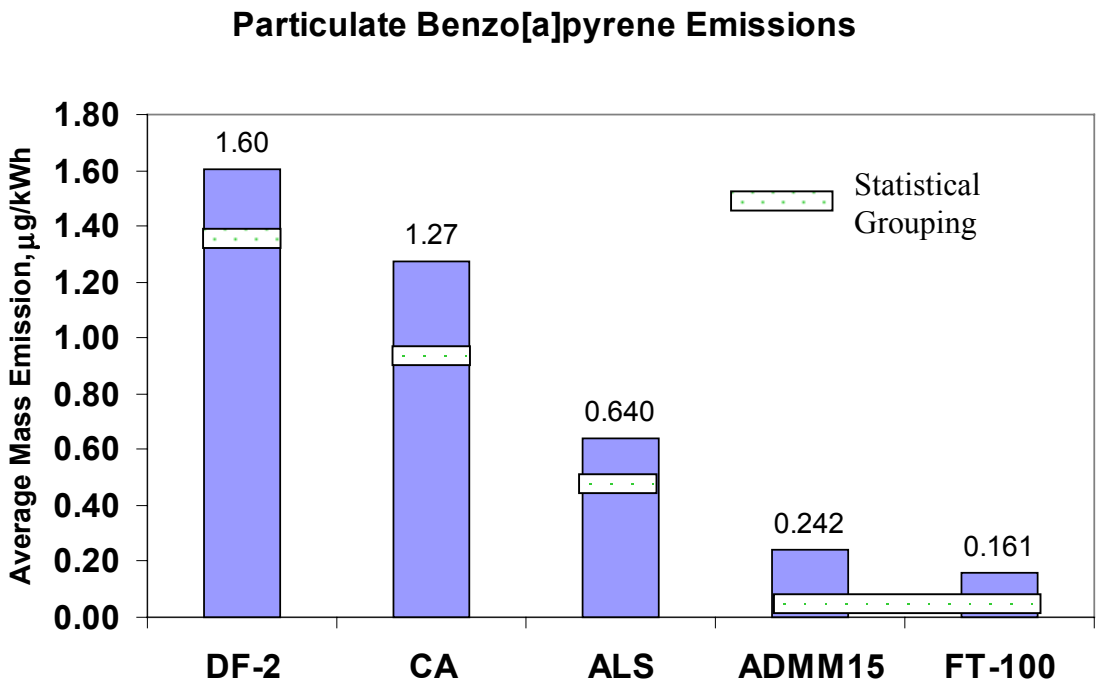


Figure 93. Test Fuel Average Particulate Phase Benzo[a]pyrene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

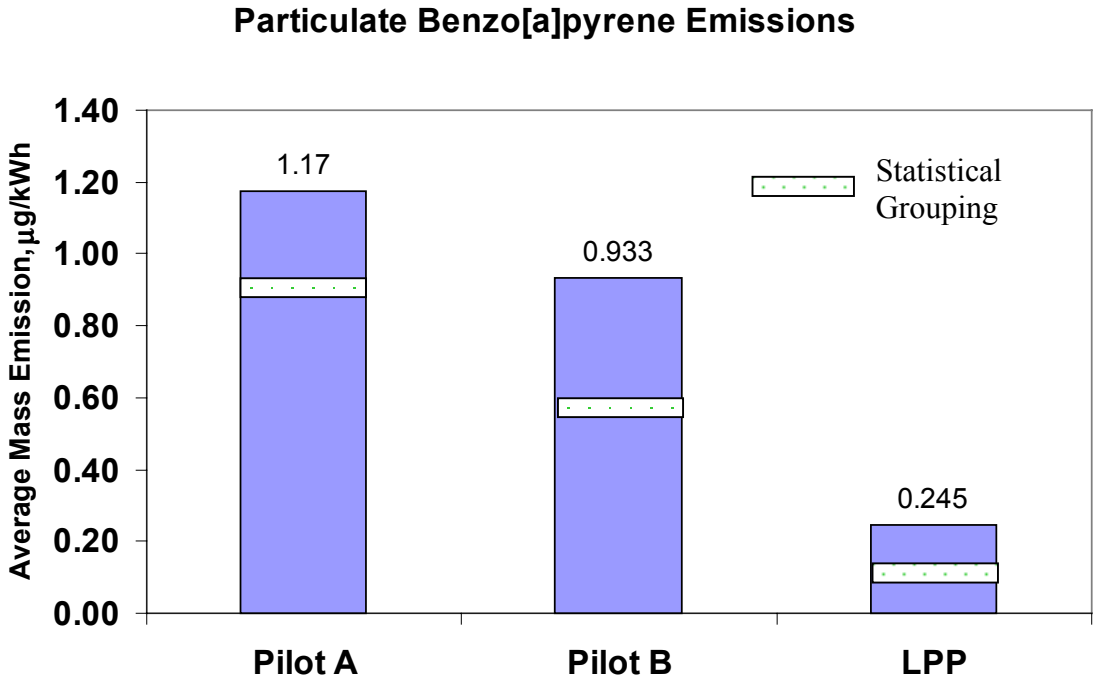


Figure 94. Pilot Condition Average Particulate Phase Benzo[a]pyrene Mass Emissions for Test Fuels and Modes (µg/kWh)

Statistically significant differences exist in the average indeno(1,2,3-cd)pyrene among the pilot conditions, fuels, pilot condition*fuel interaction, pilot condition*mode interaction, and the three-factor interaction pilot condition*fuel*mode. The average indeno(1,2,3-cd)pyrene for the DF-2 and CA fuels are significantly different from one another and the remaining two fuels, Figure 95. The average indeno(1,2,3-cd)pyrene for the FT-100 and ADMM15 fuels are not significantly different from one another.

The average indeno(1,2,3-cd)pyrene for the three pilot conditions are significantly different from one another, Figure 96.

There is no significant difference in the average indeno(1,2,3-cd)pyrene among the two modes.

The trends in the average indeno(1,2,3-cd)pyrene across the pilot conditions for the CA and DF-2 fuels are significantly different than the trends for the remaining two fuels. The average indeno(1,2,3-cd)pyrene for the CA and DF-2 fuels at the Pilot A condition are significantly different than the ADMM15 and FT-100 fuels.

The average indeno(1,2,3-cd)pyrene at the Pilot A condition for mode 10 is significantly different than mode 11.

There is no significant interaction in the average indeno(1,2,3-cd)pyrene among the fuel and mode combinations.

7.3.16 Dibenzo[a,h]anthracene

For the PAH dibenzo[a,h]anthracene there was interference in the chromatograms from all test fuel extracts. The high-resolution instrument was only used on those extracts when the LPP control condition was utilized. There were numerous non-detects for dibenzo[a,h]anthracene at the conditions with pilot fuel injection enabled for all test fuels. Thus insufficient data existed to perform the ANOVA for dibenzo[a,h]anthracene.

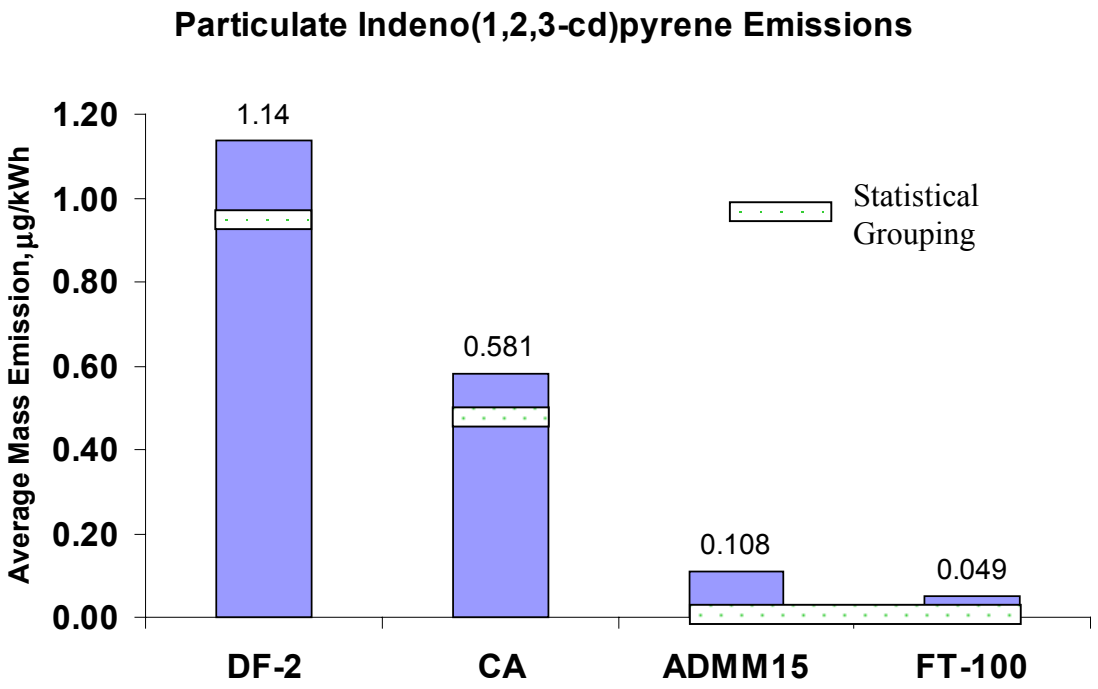


Figure 95. Test Fuel Average Particulate Phase Indeno(1,2,3-cd)pyrene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

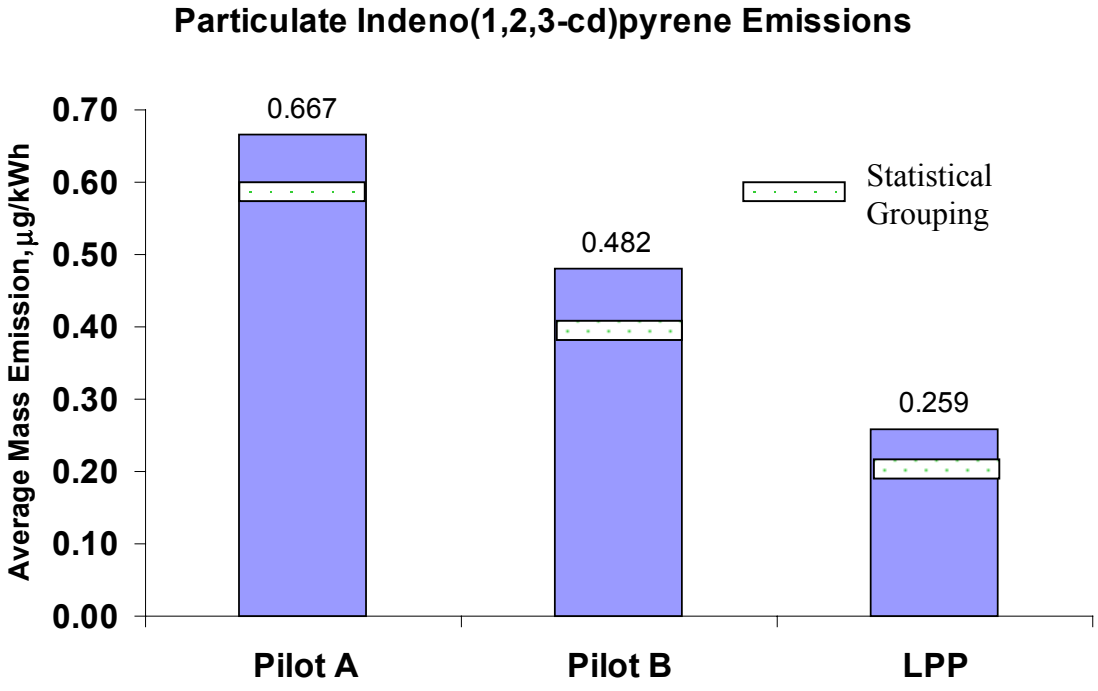


Figure 96. Pilot Condition Average Particulate Phase Indeno(1,2,3-cd)pyrene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.3.17 Benzo[ghi]perylene

For the PAH benzo[ghi]perylene, sufficient interference in the chromatograms from the ALS fuel extracts for the pilot conditions existed that there were numerous non-detects with the low-resolution mass spectrometer. The high-resolution instrument was only used on those extracts when the LPP control condition was utilized AND that did not have a benzo[a]pyrene response. The ALS fuel at the LPP control condition had low-resolution response for benzo[a]pyrene, but non-detects for benzo[ghi]perylene. There were also numerous non-detects at the conditions with pilot fuel injection enabled. The ALS fuel was not included in the ANOVA for benzo[ghi]perylene.

Statistically significant differences were apparent in the average benzo[ghi]perylene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, pilot condition*mode interaction, and the three-factor interaction pilot condition*fuel*mode. The average benzo[ghi]perylene for the DF-2 and CA fuels are significantly different from one another and the remaining two fuels. The average benzo[ghi]perylene for the FT-100 and ADMM15 fuels are not significantly different from one another, Figure 97.

The average benzo[ghi]perylene for the three pilot conditions shown in Figure 98, are significantly different from one another.

The average benzo[ghi]perylene for mode 10 is significantly different than mode 11.

The trends in the average benzo[ghi]perylene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining two fuels. The average benzo[ghi]perylene for the CA and DF-2 fuels at the Pilot A condition are significantly different than the ADMM15 and FT-100 fuels.

The average benzo[ghi]perylene at the Pilot A condition for mode 10 is significantly different than mode 11.

There is no significant interaction in the average benzo[ghi]perylene among the fuel and mode combinations.

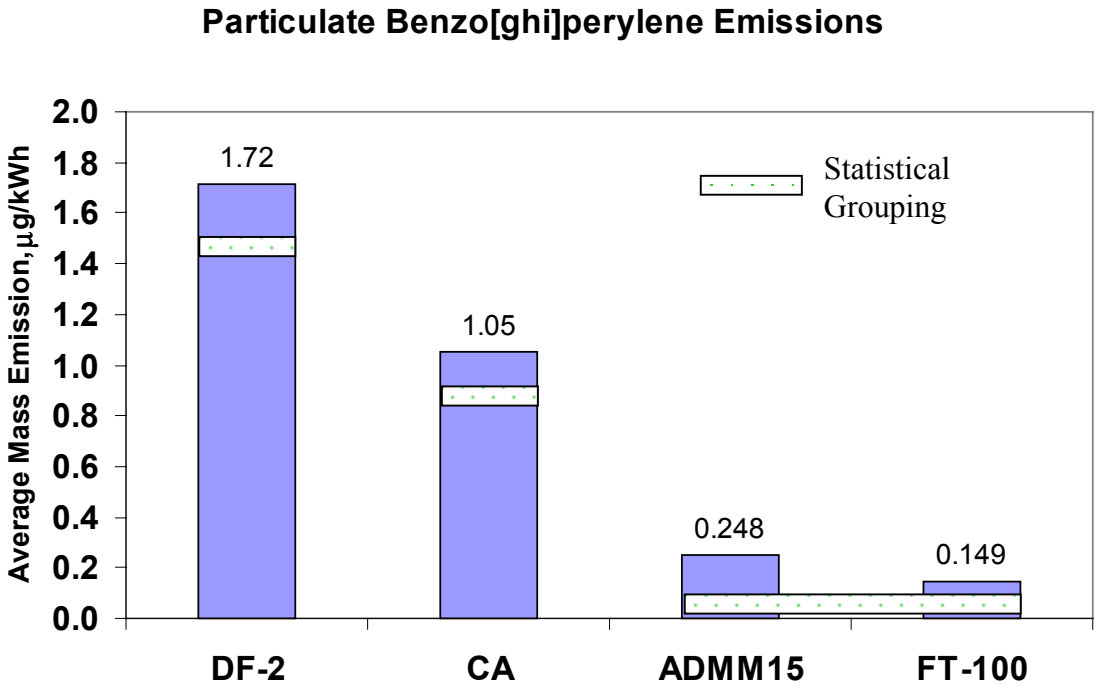


Figure 97. Test Fuel Average Particulate Phase Benzo[ghi]perylene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

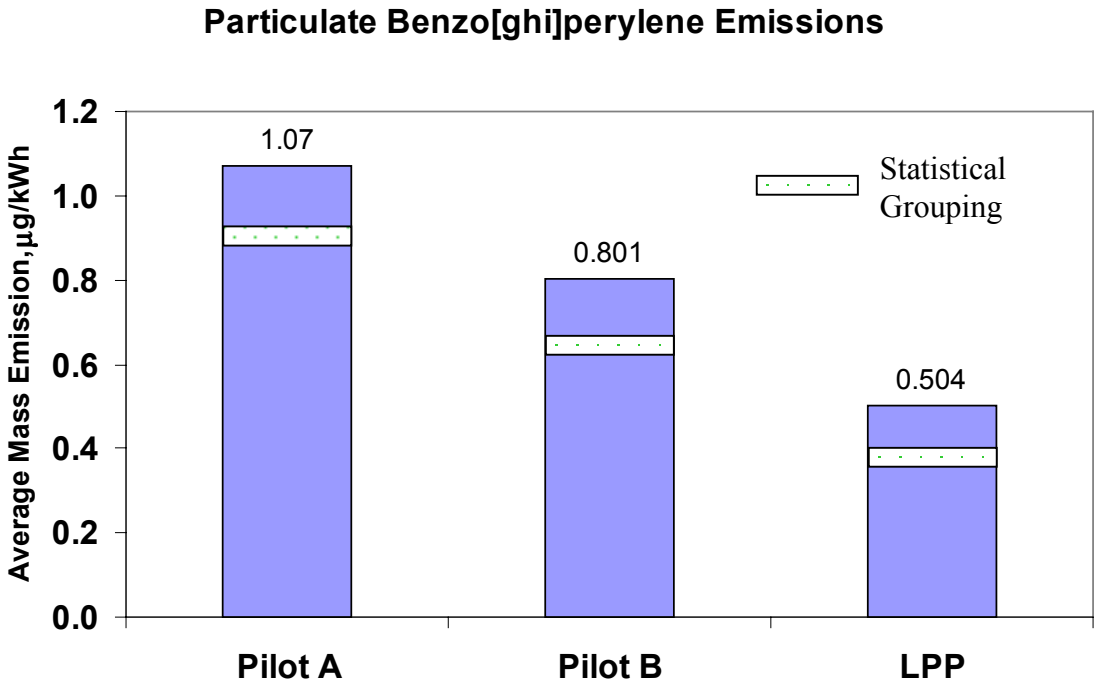


Figure 98. Pilot Condition Average Particulate Phase Benzo[ghi]perylene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.4 Fuel Impact on Gaseous PAH Species

Table 27 summarizes the general rank order of the fuels for the gas phase PAH mass emissions across the three pilot control conditions and two modes. The table displays the fuels rank from highest response to lowest response for the Least-Square means for the analysis. In general, ADMM15 and FT-100 are in the lowest statistically significant emissions grouping. Statistically significant similar fuel groupings are shown for each emission response in Table 27.

Table 27 includes the pilot condition severity across fuels and modes for each gaseous PAH compound. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average gaseous PAH compound emissions at each pilot condition. The pilot condition severity for most compounds suggests LPP operation results in the lowest PAH emissions; however, the rankings differ for some compounds.

The mode severity across fuels and pilot condition for each toxin is also in Table 27. Included are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the average gaseous PAH emissions at each mode. The mode ranking depends on the compound. The Fuel*Pilot, Fuel*Mode, Pilot*Mode, and Fuel*Pilot*Mode interactions are indicated in Table 27 for each compound.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for the pilot fuel injection study, and refer to the results in Table 27. The ANOVA tables for the pilot fuel injection evaluations can be found in Appendix F.

7.4.1 Naphthalene

Statistically significant differences were noted in the average naphthalene among the fuels, modes, pilot conditions, the pilot condition*fuel interaction, and the fuel*mode interaction. The average naphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels. The ALS and FT-100 fuels demonstrate significantly different average naphthalene; however, neither one of these fuels was significantly different than the ADMM15 fuel.

The average naphthalene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition as shown in Figure 100.

Table 27. Gaseous Phase PAH Mass Emissions (µg/kWh) for Control/Pilot Fuel Injection Study										
Response	Five Fuels, Three Pilot Conditions, Modes 10 and 11									
	Fuel	LS Means[1]	Significant Fuel Groups[2]	Pilot Condition	LS Means[1]	Significant Pilot Groups[2]	Mode	LS Means[1]	Significant Mode Groups[2]	Significant Interactions
Naphthalene	CA	7813	A	Pilot A	3417	A	10	3347	A	Pilot*Fuel Fuel*Mode
	DF-2	5046	B	Pilot B	3350	A	11	2804	B	
	ALS	1323	C	LPP	2459	B				
	ADMM15	872.0	CD							
	FT-100	323.9	D							
2-Methylnaphthalene	DF-2	6870	A	Pilot B	2929	A	10	2687	NS	Pilot*Fuel Fuel*Mode
	CA	4869	B	Pilot A	2800	A	11	2514		
	ALS	802.9	C	LPP	2072	B				
	ADMM15	376.4	C							
	FT-100	84.62	C							
1-Methylnaphthalene	DF-2	4869	A	Pilot B	1922	A	10	1723	NS	Pilot*Fuel Fuel*Mode
	CA	2868	B	Pilot A	1848	A	11	1655		
	ALS	468.0	C	LPP	1297	B				
	ADMM15	185.7	C							
	FT-100	53.49	C							
2,6-Dimethylnaphthalene	DF-2	4930	A	Pilot B	1570	A	11	1373	NS	Pilot*Fuel
	CA	1430	B	Pilot A	1404	AB	10	1304		
	ALS	237.6	C	LPP	1041	B				
	ADMM15	61.71	C							
	FT-100	33.12	C							
Acenaphthylene	DF-2	606.1	A	Pilot A	282.3	A	10	227.6	NS	Pilot*Fuel
	CA	239.2	B	Pilot B	259.3	A	11	226.2		
	ALS	147.4	BC	LPP	139.0	B				
	ADMM15	89.68	C							
	FT-100	52.04	C							
Acenaphthene	DF-2	723.2	A	Pilot B	213.5	NS	11	200.4	NS	NS
	CA	137.5	B	Pilot A	203.4		10	176.3		
	ALS	48.29	BC	LPP	148.1					
	ADMM15	24.81	BC							
	FT-100	7.888	C							

Table 27. Gaseous Phase PAH Mass Emissions (µg/kWh) for Control/Pilot Fuel Injection Study (contd)										
Response	**Five Fuels, Three Pilot Conditions, Modes 10 and 11**									
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**	**Pilot Condition**	**LS Means[1]**	**Significant Pilot Groups[2]**	**Mode**	**LS Means[1]**	**Significant Mode Groups[2]**	**Significant Interactions**
Fluorene	DF-2	1152	A	Pilot B	323.5	NS	11	307.8	NS	NS
	CA	193.0	B	Pilot A	292.4		10	264.4		
	ALS	50.08	B	LPP	242.3					
	ADMM15	21.51	B							
	FT-100	14.25	B							
Phenanthrene	DF-2	1815	A	Pilot A	604.4	NS	11	535.7	NS	Pilot*Fuel
	CA	557.6	B	Pilot B	545.9		10	510.0		
	ALS	169.2	C	LPP	418.4					
	ADMM15	43.16	C							
	FT-100	29.23	C							
Anthracene	DF-2	56.23	A	Pilot B	18.05	NS	10	16.93	NS	Pilot*Fuel
	CA	17.39	B	Pilot A	16.37		11	15.89		
	ALS	4.566	C	LPP	14.81					
	ADMM15	2.718	C							
	FT-100	1.144	C							
Fluoranthene	DF-2	5.871	A	LPP	4.760	A	10	3.222	NS	Pilot*Fuel
	CA	3.655	B	Pilot A	2.457	B	11	2.689		
	ALS	2.344	BC	Pilot B	1.649	B				
	FT-100	1.590	BC							
	ADMM15	1.318	C							
Pyrene	DF-2	7.599	A	LPP	5.206	A	10	3.213	NS	Pilot*Fuel
	CA	3.372	B	Pilot A	2.398	B	11	2.944		
	ALS	2.174	B	Pilot B	1.631	B				
	FT-100	1.165	B							
	ADMM15	1.081	B							

[1]Factor levels listed from highest to lowest least squares mean

[2]Letters designate groups of factor means within which there are no statistically significant differences

NS = no statistically significant differences in the mean response at the 5% level of significance

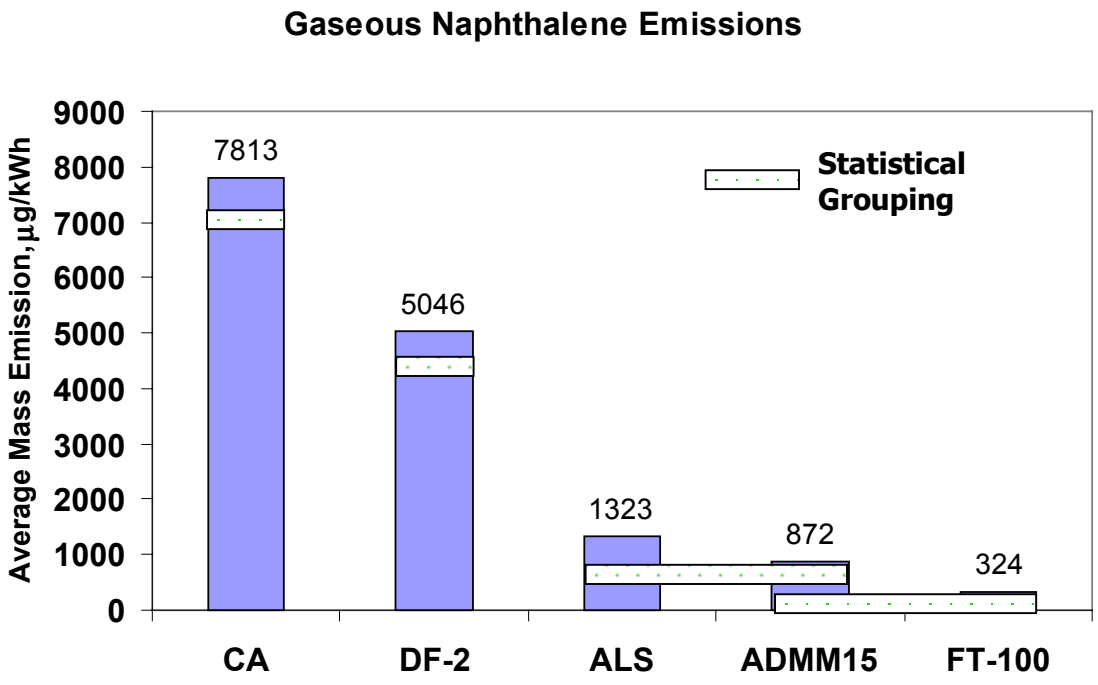


Figure 99. Test Fuel Average Gaseous Phase Naphthalene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

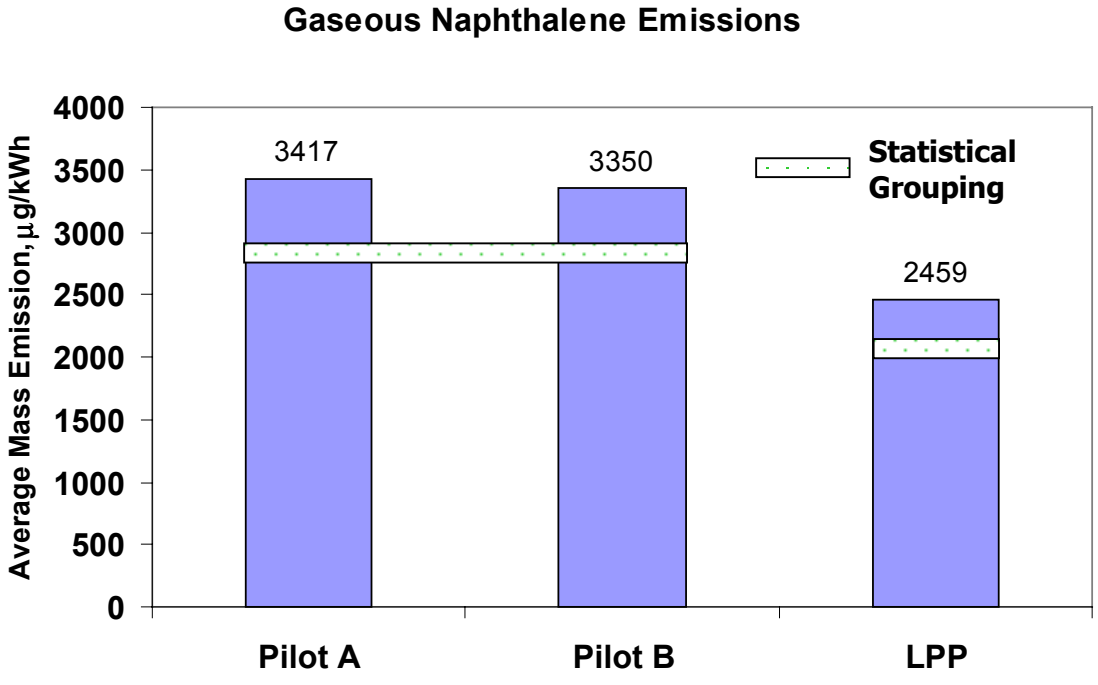


Figure 100. Pilot Condition Average Gaseous Phase Naphthalene Mass Emissions for Test Fuels and Modes (µg/kWh)

The average naphthalene for modes 10 and 11 are significantly different from one another.

The trend in the average naphthalene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trends for the CA and DF-2 fuels. Whereas, the trends in the ADMM15, ALS, and FT-100 fuels across the three pilot conditions are relatively constant, the CA and DF-2 fuels show an increase in the average naphthalene from the LPP to the Pilot A and Pilot B conditions.

There is no significant interaction in the average naphthalene among the mode and pilot condition combinations.

A significant interaction exists between the fuels and modes. The difference in the average naphthalene between the two modes is significant at the CA fuel. However, the remaining four fuels do not demonstrate a significant difference between the two modes with respect to the average naphthalene.

7.4.2 2-Methylnaphthalene

Statistically significant differences exist in the average 2-methylnaphthalene among the pilot conditions, fuels, pilot condition*fuel interaction, and the fuel*mode interaction. The average 2-methylnaphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels, Figure 101. The average 2-methylnaphthalene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.

The average 2-methylnaphthalene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition, Figure 102.

The average 2-methylnaphthalene for modes 10 and 11 are not significantly different from one another.

The trend in the average 2-methylnaphthalene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trends for the CA and DF-2 fuels. Whereas, the trends in the ADMM15, ALS, and FT-100 fuels across the three pilot conditions are relatively constant, the CA and DF-2 fuels show an increase in the average 2-methylnaphthalene from the LPP to the Pilot A and Pilot B conditions.

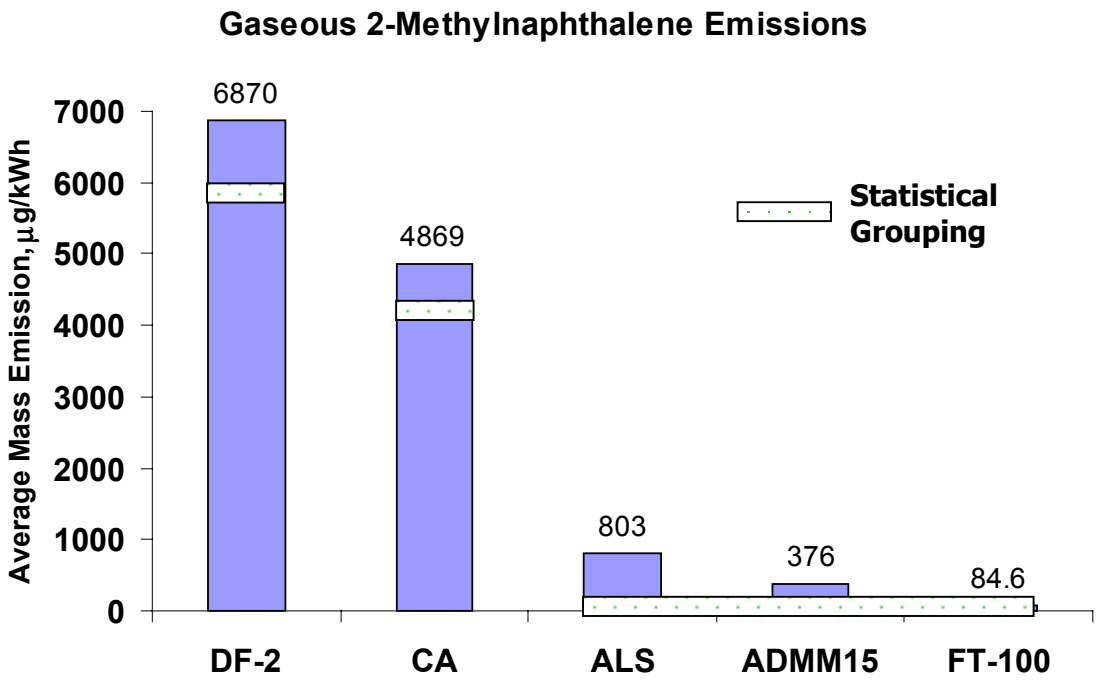


Figure 101. Test Fuel Average Gaseous Phase 2-Methylnaphthalene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

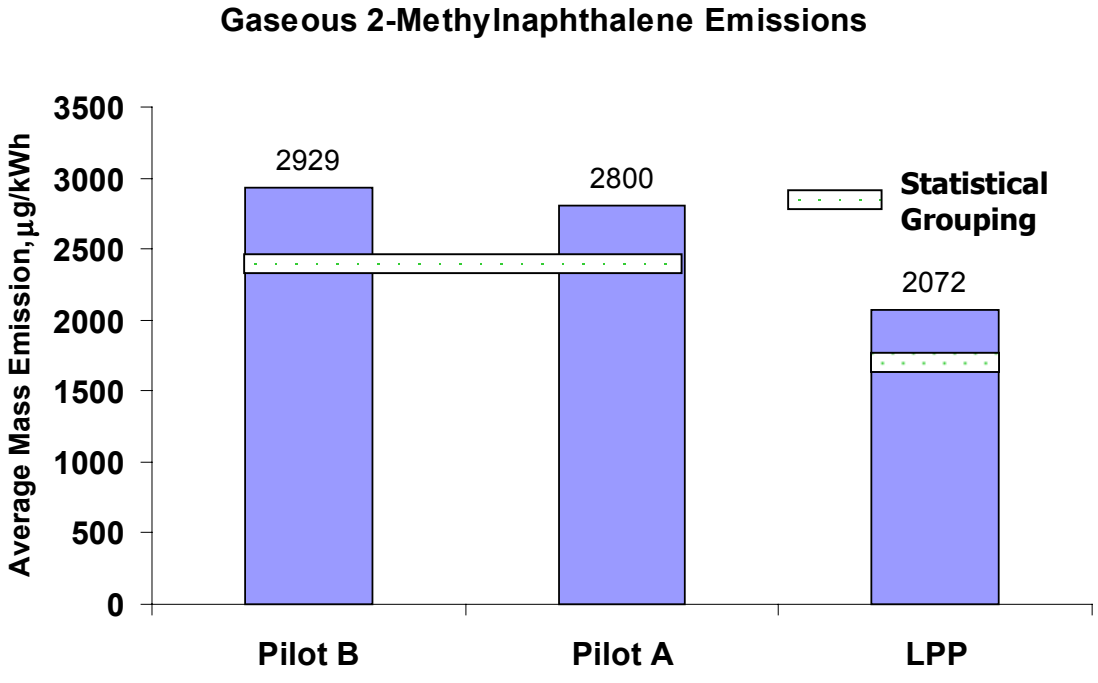


Figure 102. Pilot Condition Average Gaseous Phase 2-Methylnaphthalene Mass Emissions for Test Fuels and Modes (µg/kWh)

There is not any significant interaction in the average 2-methylnaphthalene among the mode and pilot condition combinations.

A significant interaction exists between the fuels and modes. The difference in the average 2-methylnaphthalene between the two modes is significant at the CA fuel. However, the remaining four fuels do not demonstrate a significant difference between the two modes with respect to the average 2-methylnaphthalene.

7.4.3 1-Methylnaphthalene

Statistically significant differences were apparent in the average 1-methylnaphthalene among the pilot conditions, fuels, pilot condition*fuel interaction, and fuel*mode interaction. The average 1-methylnaphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels, Figure 103. The average 1-methylnaphthalene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.

In Figure 104, the average 1-methylnaphthalene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.

The average 1-methylnaphthalene for modes 10 and 11 is not significantly different from one another.

The trend in the average 1-methylnaphthalene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trends for the CA and DF-2 fuels. Whereas, the trends in the ADMM15, ALS, and FT-100 fuels across the three pilot conditions are relatively constant, the CA and DF-2 fuels show an increase in the average 1-methylnaphthalene from the LPP to the Pilot A and Pilot B conditions.

There is no significant interaction in the average 1-methylnapthalene among the mode and pilot condition combinations.

A significant interaction exists between the fuels and modes. The difference in the average 1-methylnaphthalene between the two modes is significant at the CA fuel. However, the remaining four fuels do not demonstrate a significant difference between the two modes with respect to the average 1-methylnaphthalene.

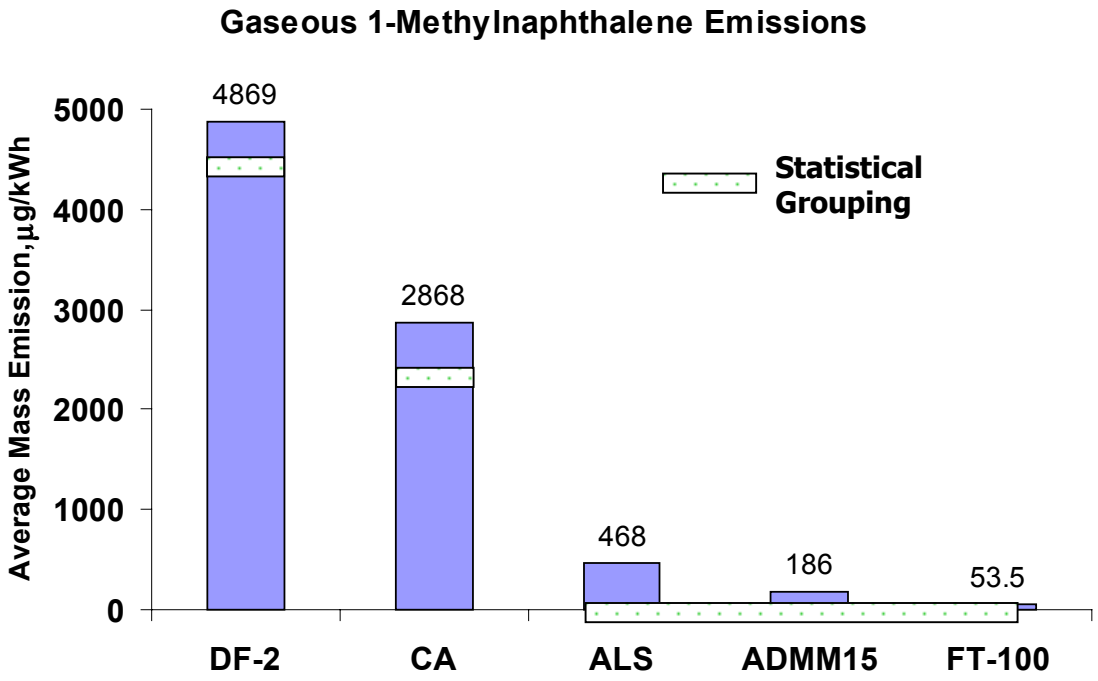


Figure 103. Test Fuel Average Gaseous Phase 1-Methylnaphthalene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

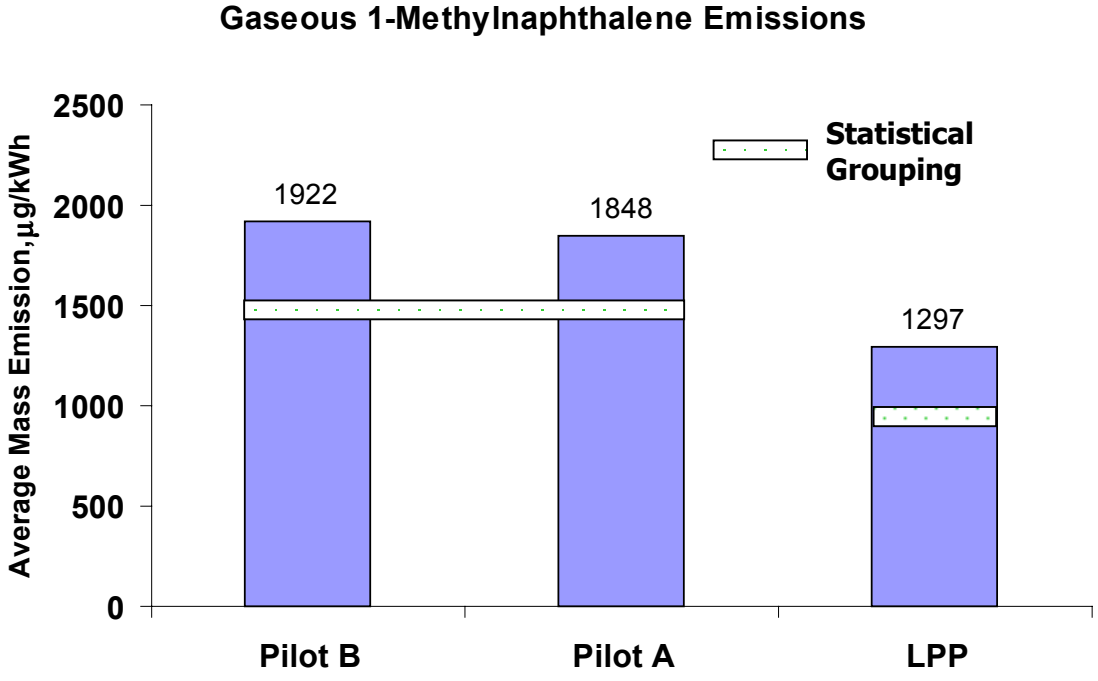


Figure 104. Pilot Condition Average Gaseous Phase 1-Methylnaphthalene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.4.4 2,6-Dimethylnaphthalene

Statistically significant differences were noted in the average 2,6-dimethylnaphthalene among the pilot conditions, fuels, and pilot condition*fuel interaction. The average 2,6-dimethylnaphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels. The average 2,6-dimethylnaphthalene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another, Figure 105.

In Figure 106, the average 2,6-dimethylnaphthalene for the Pilot B condition is significantly different than the LPP condition.

The average 2,6-dimethylnaphthalene for modes 10 and 11 are not significantly different from one another.

The trend in the average 2,6-dimethylnaphthalene across the pilot conditions for the ADMM16, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average 2,6-dimethylnaphthalene from the LPP to the Pilot A and Pilot B conditions.

There is no significant interaction in the average 2,6-dimethylnaphthalene among the pilot condition and mode combinations.

There is no significant interaction in the average 2,6-dimethylnaphthalene among the fuel and mode combinations.

7.4.5 Acenaphthylene

Statistically significant differences exist in the average acenaphthylene among the pilot conditions, fuels, and pilot condition*fuel interaction. There are several distinct fuel groupings with respect to the average acenaphthylene. The average acenaphthylene for the DF-2 fuel is significantly different from the remaining four fuels, Figure 107. The CA fuel is significantly different than the ADMM15 and FT-100 fuels, but not significantly different than the ALS fuel.

The average acenaphthylene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP conditions, Figure 108.

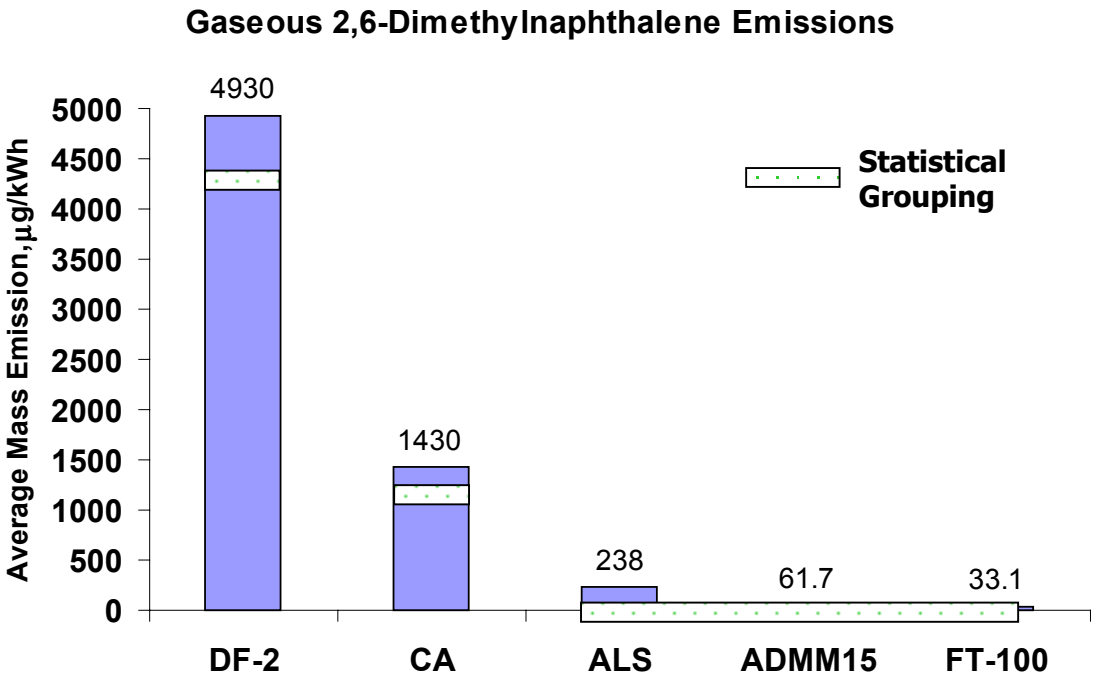


Figure 105. Test Fuel Average Gaseous Phase 2,6-Dimethylnaphthalene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

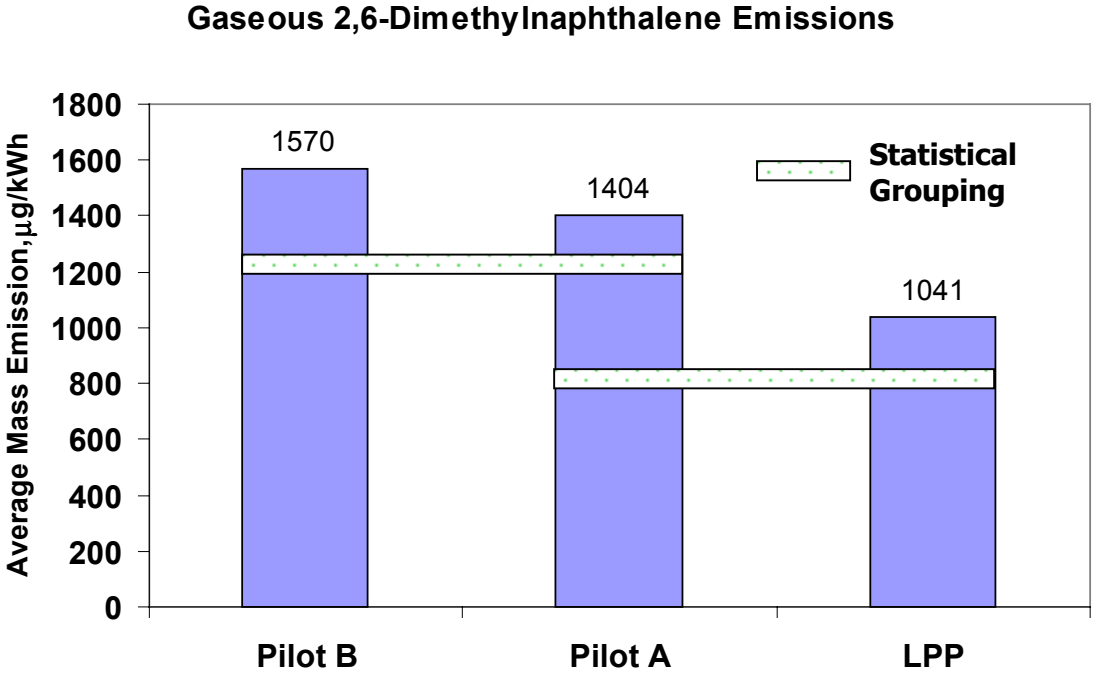


Figure 106. Pilot Condition Average Gaseous Phase 2,6-Dimethylnaphthalene Mass Emissions for Test Fuels and Modes (µg/kWh)

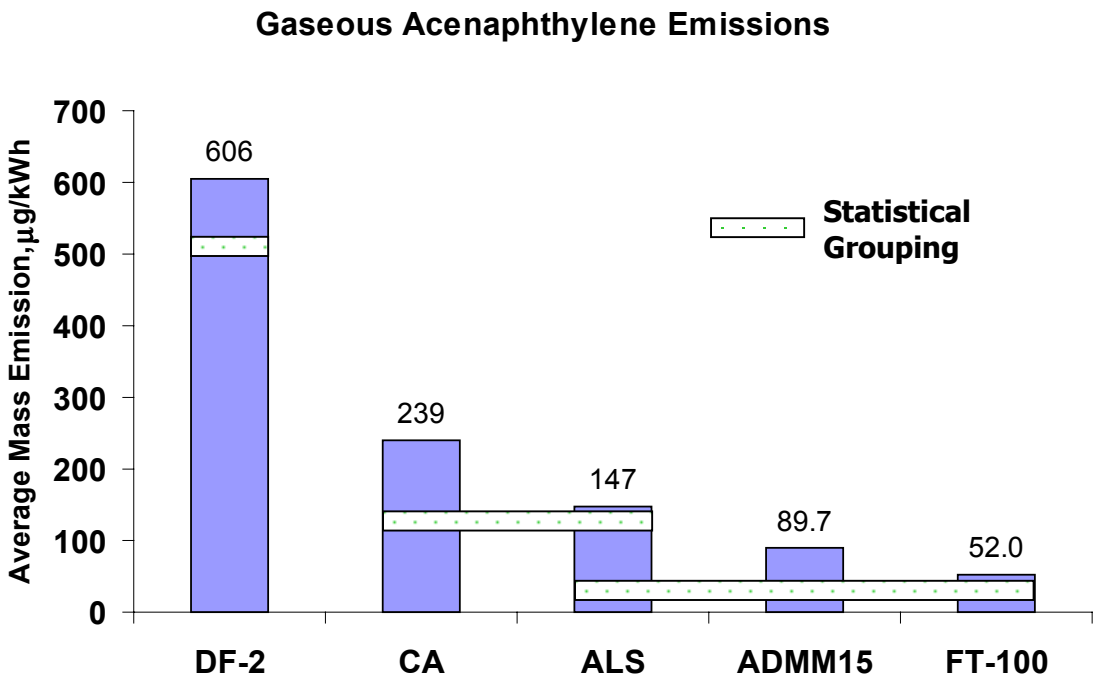


Figure 107. Test Fuel Average Gaseous Phase Acenaphthylene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

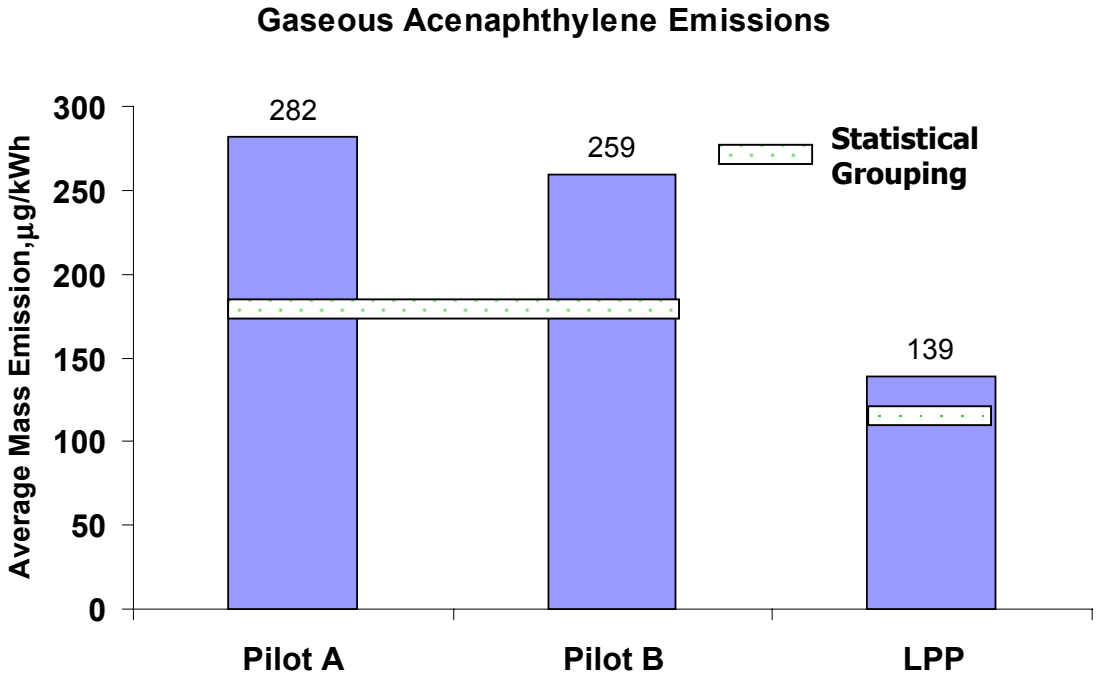


Figure 108. Pilot Condition Average Gaseous Phase Acenaphthylene Mass Emissions for Test Fuels and Modes (µg/kWh)

The average acenaphthylene for modes 10 and 11 are not significantly different from one another.

The trend in the average acenaphthylene across the pilot conditions for the ADMM15, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average acenaphthylene from the LPP to the Pilot A and Pilot B conditions.

There is no significant interaction in the average acenaphthylene among the pilot condition and mode combinations.

There is no significant interaction in the average acenaphthylene among the fuel and mode combinations.

7.4.6 Acenaphthene

Statistically significant differences were apparent in the average acenaphthene among the fuels. There are several distinct fuel groupings with respect to the average acenaphthene. The average acenaphthene for the DF-2 fuel is significantly different than the remaining four fuels. Also, the CA fuel is significantly different than the FT-100 fuel, but not significantly different than the ADMM15 or ALS fuels, Figure 109.

The average acenaphthene in Figure 110 for the three pilot conditions are not significantly different from one another.

The average acenaphthene for modes 10 and 11 are not significantly different from one another.

There is no significant interaction in the average acenaphthene among the fuel and pilot condition combinations, the mode and pilot condition combinations, and the fuel and mode combinations.

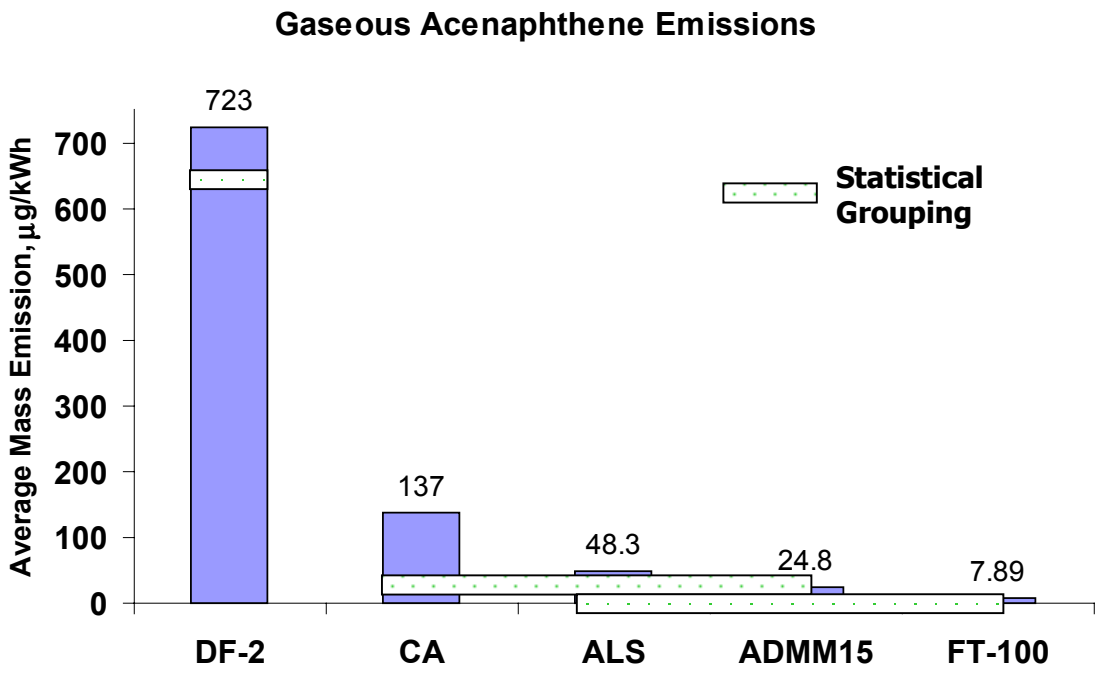


Figure 109. Test Fuel Average Gaseous Phase Acenaphthene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

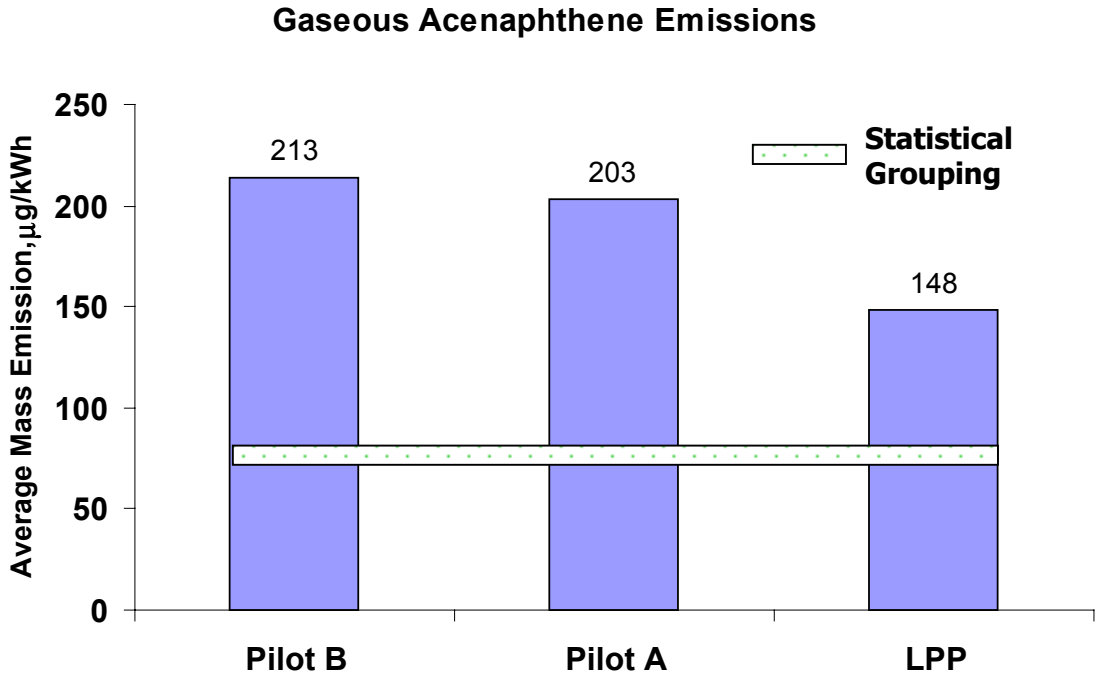


Figure 110. Pilot Condition Average Gaseous Phase Acenaphthene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.4.7 Fluorene

Statistically significant differences exist for the average fluorene among the fuels. The average fluorene for the DF-2 fuel is significantly different than the remaining four fuels, Figure 111.

From Figure 112, the average fluorene for the three pilot conditions are not significantly different from one another.

The average fluorene for modes 10 and 11 are not significantly different from one another.

There is no significant interaction in the average fluorene among the fuel and pilot condition combinations, the pilot condition and mode combinations, and the fuel and mode combinations.

7.4.8 Phenanthrene

Statistically significant differences were noted in the average phenanthrene among the fuels and pilot condition*fuel interaction. The average phenanthrene for the DF-2 and CA fuels is significantly different than the remaining three fuels shown in Figure 113. The average phenanthrene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.

There is no significant difference in the average phenanthrene among the three pilot conditions as shown in Figure 114.

The average phenanthrene for modes 10 and 11 are not significantly different from one another.

The trend in the average phenanthrene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trend for the DF-2 and CA fuels. Whereas, the trends in the ADMM15, ALS, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average phenanthrene from the LPP to the Pilot A and Pilot B conditions. Also, the CA fuel demonstrates an increase in the Pilot A condition.

There is no significant interaction in the average phenanthrene among the pilot conditions and mode combinations or among the fuel and mode combinations.

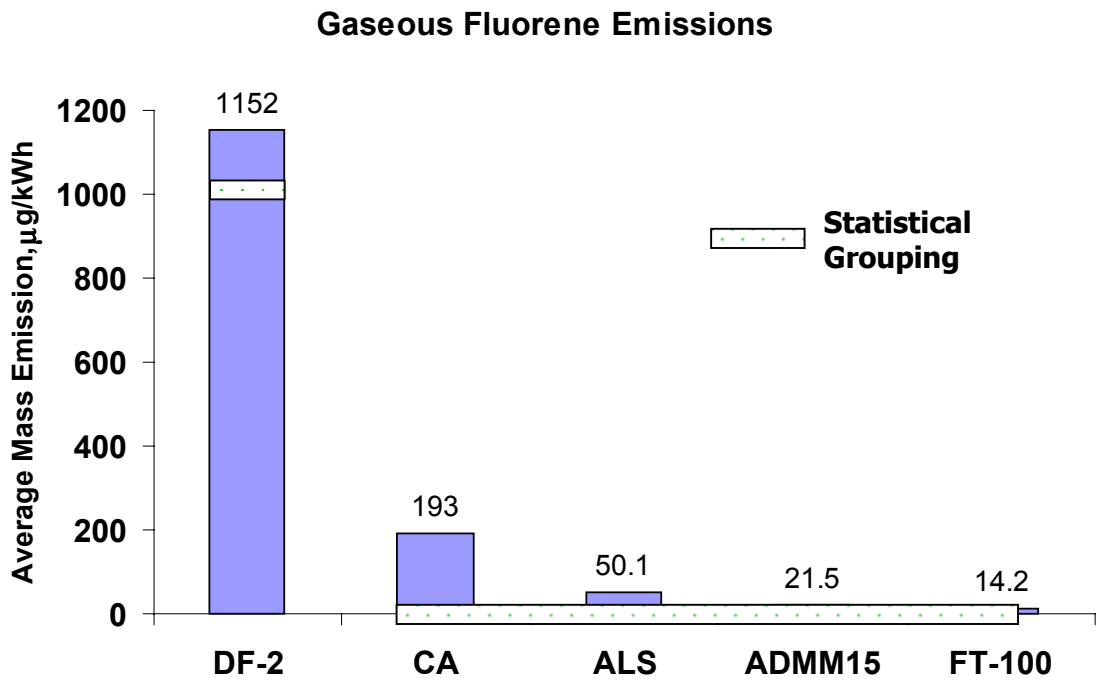


Figure 111. Test Fuel Average Gaseous Phase Fluorene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

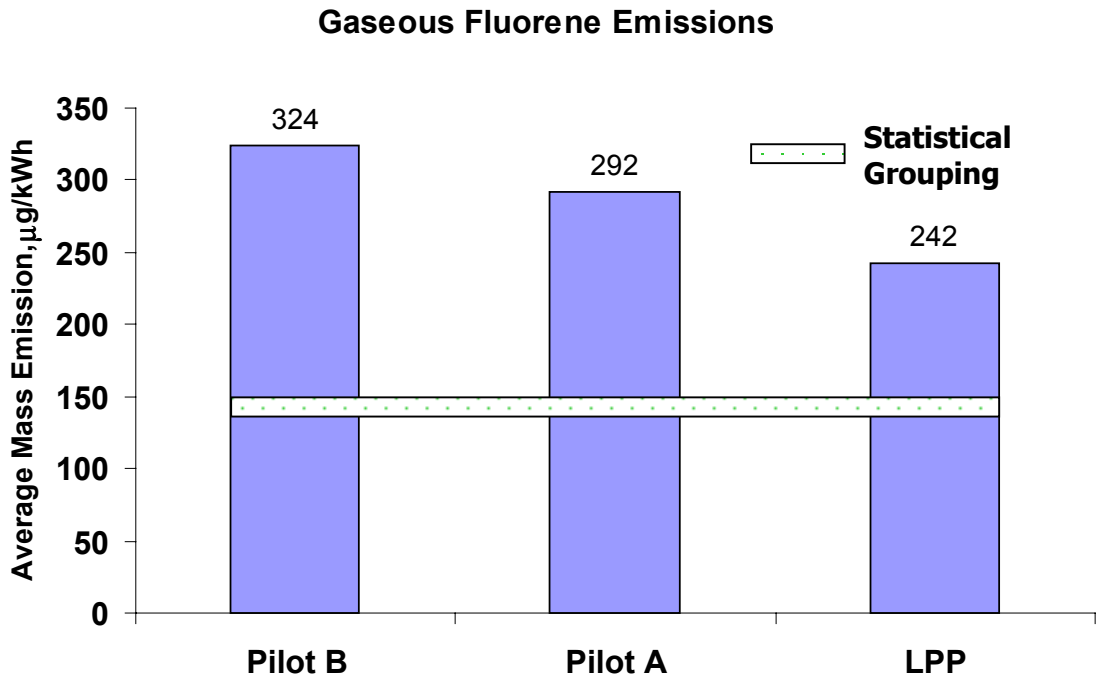


Figure 112. Pilot Condition Average Gaseous Phase Fluorene Mass Emissions for Test Fuels and Modes (µg/kWh)

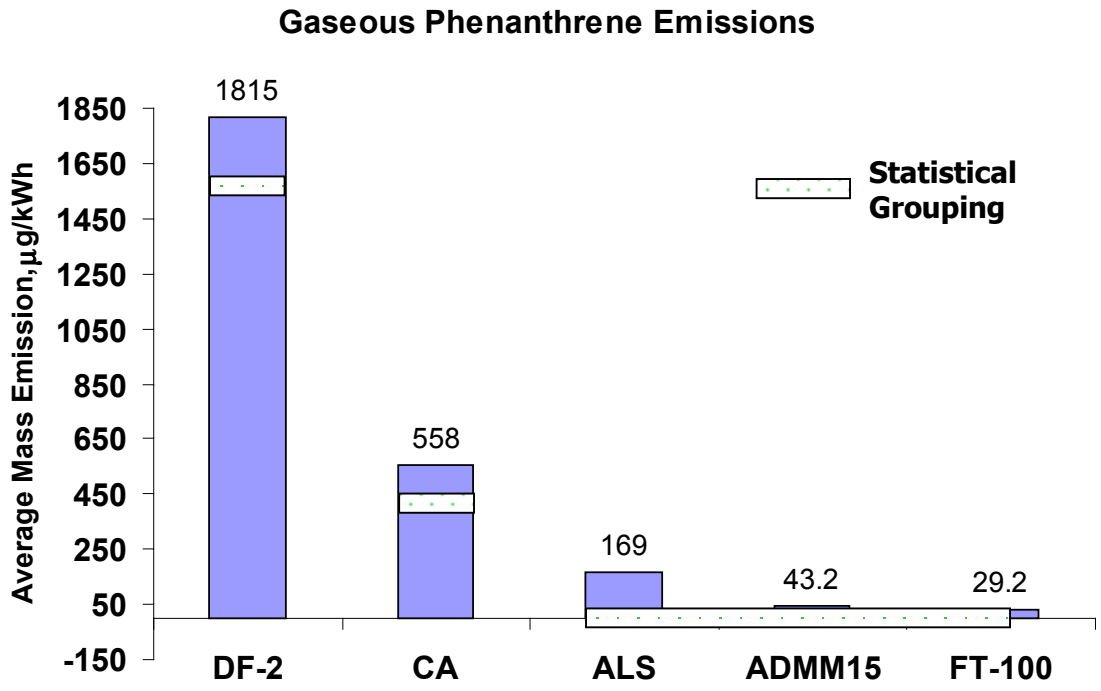


Figure 113. Test Fuel Average Gaseous Phase Phenanthrene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

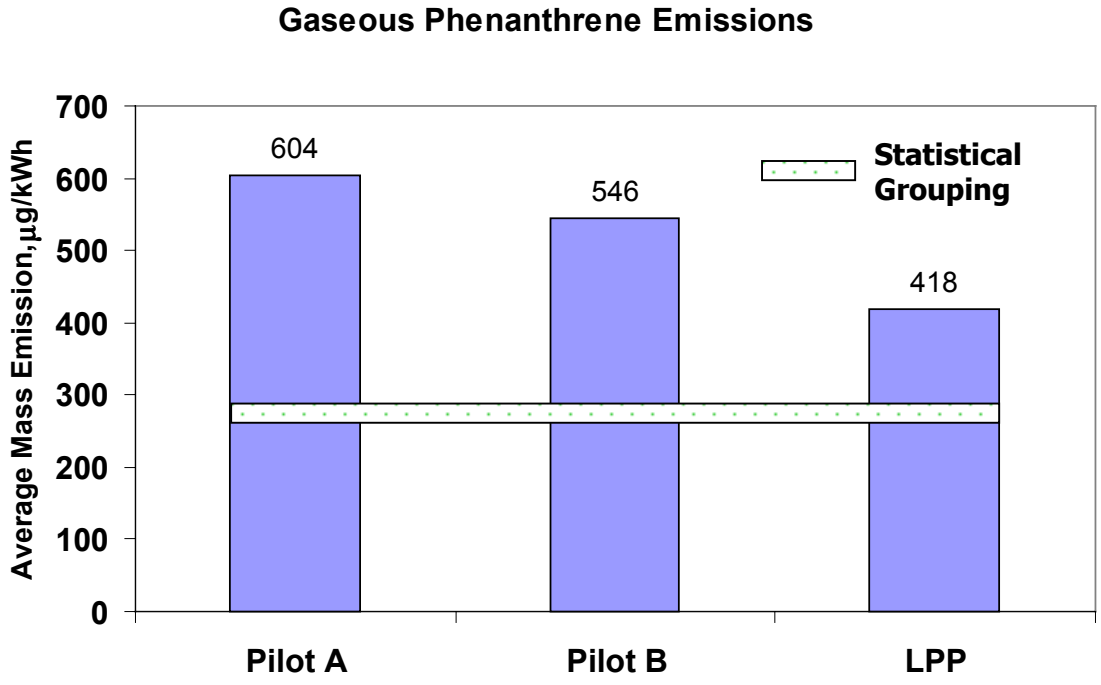


Figure 114. Pilot Condition Average Gaseous Phase Phenanthrene Mass Emissions for Test Fuels and Modes (µg/kWh)

7.4.9 Anthracene

Statistically significant differences were apparent in the average anthracene among the fuels and pilot condition*fuel interaction. The average anthracene for the DF-2 and CA fuels is significantly different than the remaining three fuels shown in Figure 115. The average anthracene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.

There are no significant differences in the average anthracene among the three pilot conditions as shown in Figure 116.

The average anthracene for modes 10 and 11 are not significantly different from one another.

The trend in the average anthracene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trend for the DF-2 and CA fuels. Whereas, the trends in the ADMM15, ALS, and FT-100 fuels are relatively constant, the DF-2 fuel demonstrates a slight increase from the LPP to the Pilot B condition. Also, the CA fuel shows an increase in the Pilot A condition.

There is no significant interaction in the average anthracene among the pilot condition and mode combinations or among the fuel and mode combinations.

7.4.10 Fluoranthene

Statistically significant differences exist in the average fluoranthene among the pilot conditions, fuels, and pilot condition*fuel interaction. There are several distinct fuel groupings with respect to the average fluoranthene as shown in Figure 117. The average fluoranthene for the DF-2 fuel is significantly different from the remaining four fuels. The CA fuel is significantly different than the ADMM15 fuel, but not significantly different than the ALS or FT-100 fuels.

The average fluoranthene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP conditions as seen in Figure 118.

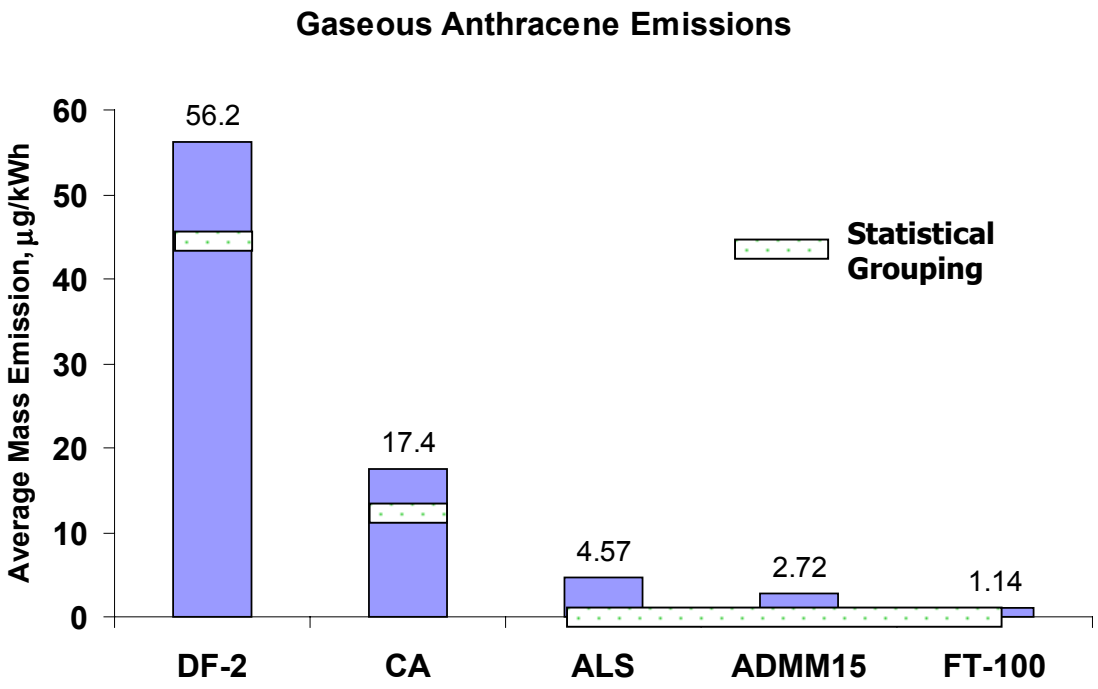


Figure 115. Test Fuel Average Gaseous Phase Anthracene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

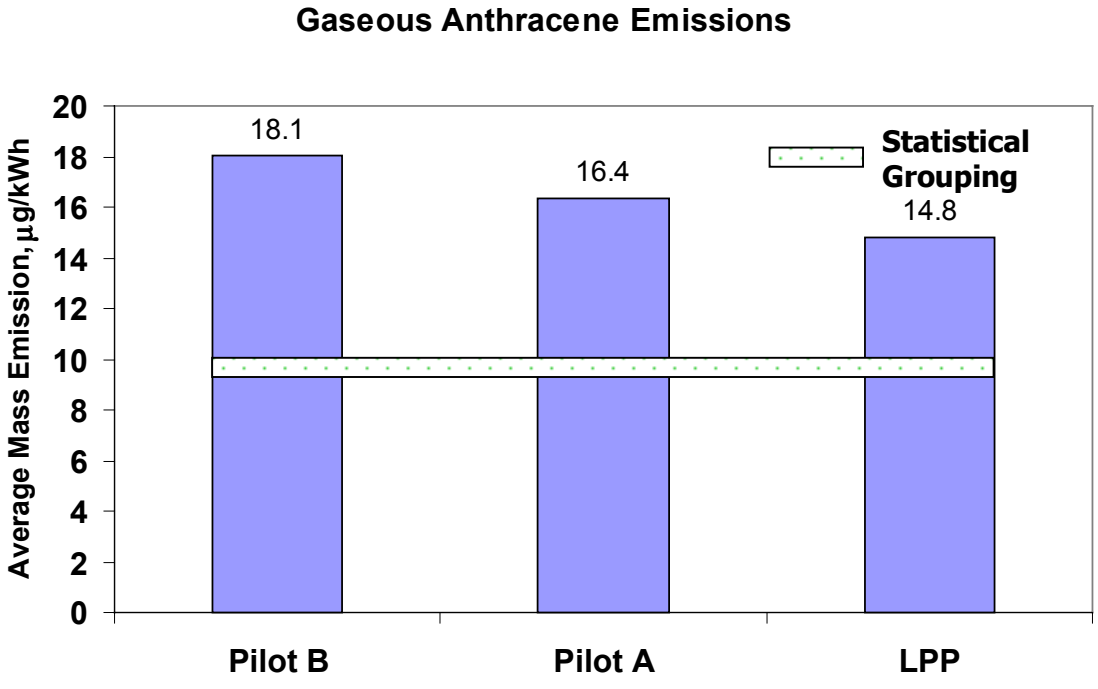


Figure 116. Pilot Condition Average Gaseous Phase Anthracene Mass Emissions for Test Fuels and Modes (µg/kWh)

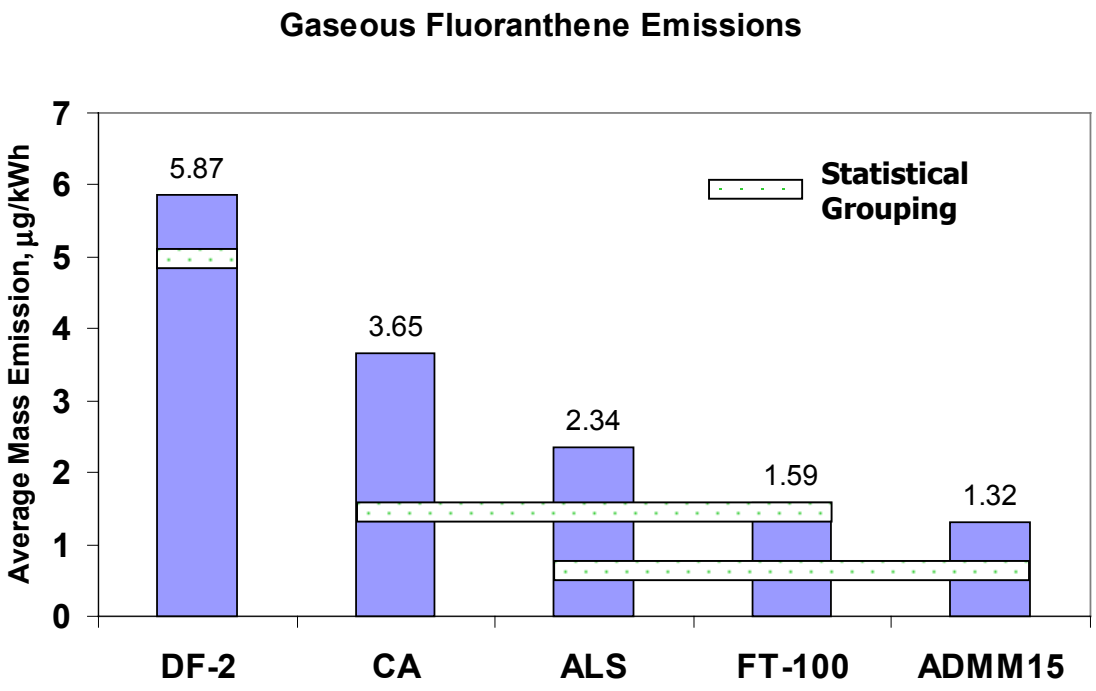


Figure 117. Test Fuel Average Gaseous Phase Fluoranthene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

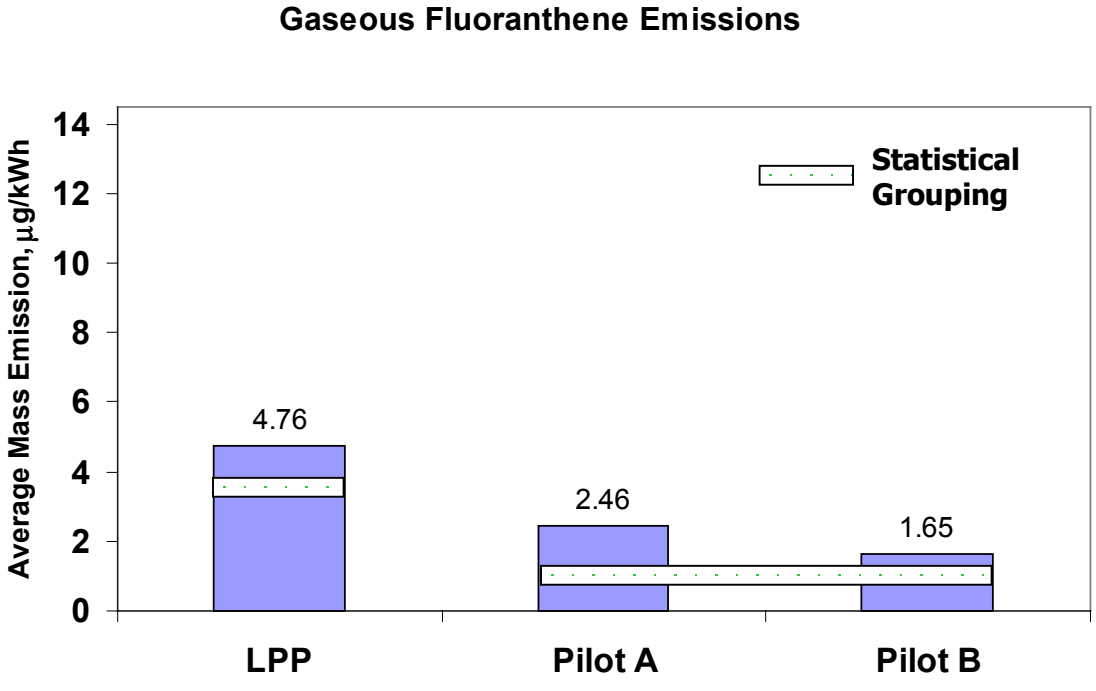


Figure 118. Pilot Condition Average Gaseous Phase Fluoranthene Mass Emissions for Test Fuels and Modes (µg/kWh)

The average fluoranthene for modes 10 and 11 are not significantly different from one another.

The trend in the average fluoranthene across the pilot conditions for the ADMM15, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average fluoranthene at the LPP condition.

There is no significant interaction in the average fluoranthene among the pilot condition and mode combinations or among the fuel and mode combinations.

7.4.11 Pyrene

Statistically significant differences were noted in the average pyrene among the pilot conditions, fuels, and pilot condition*fuel interaction. In Figure 119, the average pyrene for the DF-2 fuel is shown to be significantly different than the other four fuels. The average pyrene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

From Figure 120, the average pyrene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.

The average pyrene for modes 10 and 11 are not significantly different from one another.

The trend in the average pyrene across the pilot conditions for the ADMM15, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average pyrene at the LPP condition.

There is no significant interaction in the average pyrene among the pilot condition and mode combinations or among the fuel and mode combinations.

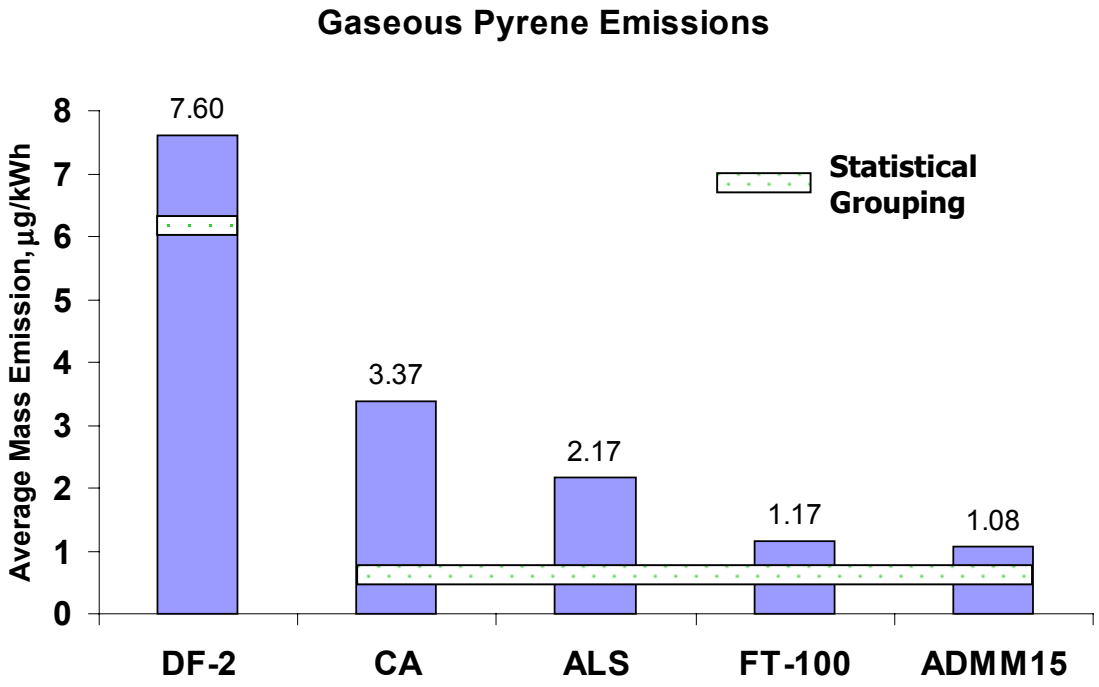


Figure 119. Test Fuel Average Gaseous Phase Pyrene Mass Emissions for Pilot Conditions and Modes (µg/kWh)

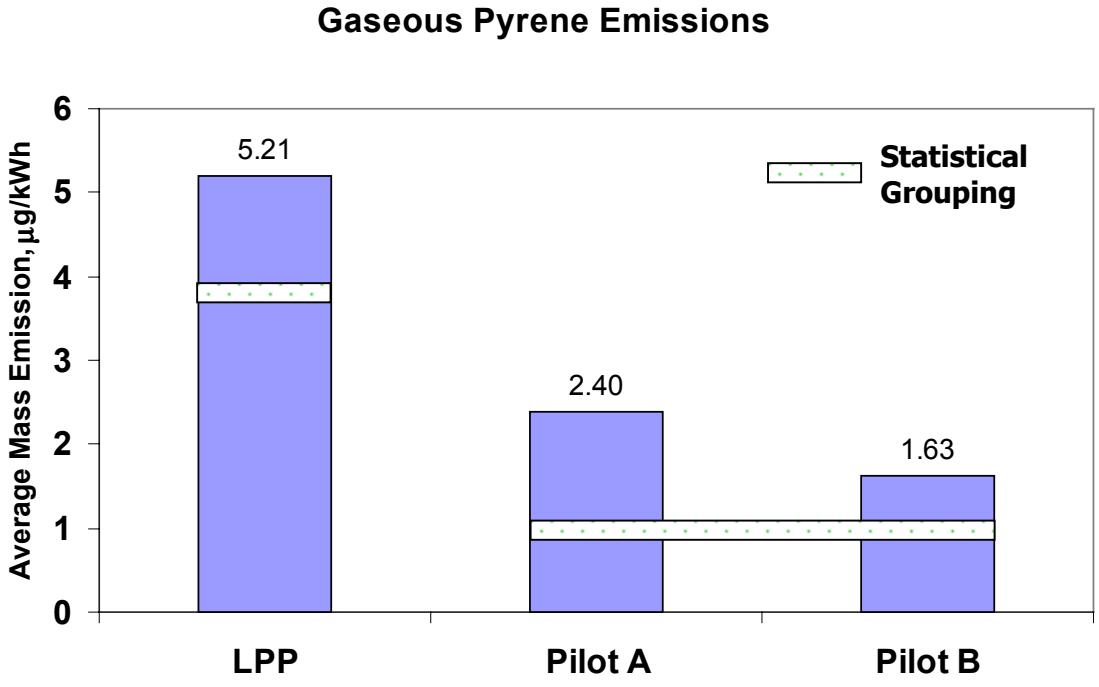


Figure 120. Pilot Condition Average Gaseous Phase Pyrene Mass Emissions for Test Fuels and Modes (µg/kWh)

8.0 FUEL IMPACT ON EMISSIONS - MODE 12 (IDLE) LPP OPERATION

Fuel comparisons were made for brake specific exhaust emissions with the engine operated under LPP control with pilot fuel injection turned off for the Mode 12 idle condition. Due to the variability of the Mode 12 data, primarily due to engine load control, the idle data was analyzed separately from the other modal data. The ANOVA tables for the Mode 12 averages can be found in Appendix G.

8.1 Fuel Impact on Regulated Brake Specific Mass Emissions

Statistically significant trends, at 95% confidence, were not apparent from an ANOVA of the Mode 12 brake specific emissions data. Table 28 summarizes the general rank order for the regulated Mode 12 mass emissions during LPP engine operation with pilot fuel injection turned off. The table displays the fuels rank from highest response to lowest response for the Least-Square means of the analysis.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for Mode 12, and refer to the results in Table 28. The ANOVA tables for the Mode 12 can be found in Appendix G.

8.1.1 Fuel Impact on Total Particulate, NO_X, HC, CO, CO_2, SOF of PM

At the 95% confidence level, no statistically significant differences were observed in the average regulated mass emissions among the test fuels at the idle condition.

8.2 Fuel Impact on Four Clean Air Act Toxic Air Pollutants

Table 29 is the ranking of the test fuels from multifactor ANOVA for the four EPA Clean Air Act toxic air pollutant compounds. For the EPA toxic air pollutants, ADMM15 and FT-100 were statistically similar emitting fuels.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response and refer to the results in Table 29. The ANOVA tables for the Mode 12 averages can be found in Appendix G.

Table 28. Mode 12 Mass Emissions (g/kWh) for LPP Operation			
Response	**LPP Only - Mode 12**		
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**
BSPM	ALS	8.860	NS
	DF-2	8.418	
	CA	6.765	
	FT-100	3.546	
	ADMM15	2.903	
$BSNO_X$	ADMM15	20.85	NS
	DF-2	19.32	
	FT-100	18.78	
	ALS	18.71	
	CA	17.30	
BSHC	ALS	54.08	NS
	DF-2	53.40	
	CA	36.86	
	ADMM15	36.76	
	FT-100	28.17	
BSCO	DF-2	195.7	NS
	ALS	190.5	
	ADMM15	159.4	
	CA	127.7	
	FT-100	106.0	
$BSCO_2$	ALS	7174	NS
	FT-100	6754	
	ADMM15	6465	
	DF-2	5665	
	CA	4960	
BSSOF	ALS	8.602	NS
	DF-2	7.866	
	CA	6.365	
	FT-100	3.168	
	ADMM15	2.838	
[1]Fuels listed from highest to lowest least squares mean			
[2]Letters designate groups of fuel means within which there are no statistically significant differences			
NS = no statistically significant differences in the mean response at the 5% level of significance			

Table 29. Clean Air Act Toxic Air Pollutant Mass Emissions (mg/kWh) for Mode 12, LPP Operation			
Response	**LPP Only - Mode 12**		
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**
Benzene	ALS	333.9	NS
	CA	249.6	
	DF-2	241.5	
	ADMM15	178.2	
	FT-100	118.0	
1,3-Butadiene	ALS	460.2	NS
	FT-100	282.9	
	DF-2	229.3	
	ADMM15	216.5	
	CA	196.9	
Formaldehyde	ALS	32241.5	NS
	DF-2	30348.2	
	ADMM15	29186.9	
	FT-100	23723.0	
	CA	18177.0	
Acetaldehyde	DF-2	13400.4	A
	ADMM15	10477.5	AB
	FT-100	8856.8	AB
	ALS	5079.8	B
	CA	2928.5	B
[1]Fuels listed from highest to lowest least squares mean			
[2]Letters designate groups of fuel means within which there are no statistically significant differences			
NS = no statistically significant differences in the mean response at the 5% level of significance			

8.2.1 Benzene, 1,3-Butadiene, Formaldehyde

At the 95% confidence level, no statistically significant differences were apparent in the average benzene, 1,3-butadiene, or formaldehyde mass emissions among the fuels at the idle condition.

8.2.2 Acetaldehyde

The average acetaldehyde for the DF-2 fuel is significantly different than the ALS and CA fuels. The ADMM15 and FT100 fuels had statistically similar results for acetaldehyde.

8.3 Fuel Impact on Particulate Soluble Extract PAH Species – Mode 12

The fuel rankings for thirteen of the particulate bound soluble phase PAH compounds are shown in Table 30. Due to non-detects, four PAH compounds had insufficient data for the ANOVA modeling. The four compounds were benzo[a]pyrene, indeno(123-cd)pyrene, dibenzo(a,h)anthracene, and benzo(ghi)perylene. For the majority of PAH compounds, DF-2 fuel was statistically different from the other test fuels. The ADMM15 and FT-100 fuels were in the statistically equivalent (95% confidence) lowest grouping for the particulate bound PAH compounds.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for Mode 12, and refer to the results in Table 30. The ANOVA tables for the Mode 12 averages can be found in Appendix G.

8.3.1 Naphthalene

No statistically significant differences were noted in the average naphthalene among the fuels.

8.3.2 Acenaphthylene

The average acenaphthylene for the DF-2 fuel is significantly different than the remaining four fuels. The average acenaphthylene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different.

8.3.3 Acenaphthene

No statistically significant differences exist in the average acenaphthene among the fuels.

8.3.4 Fluorene

The average fluorene for the DF-2 fuel is significantly different than the ALS fuel.

Table 30. Mode 12 Soluble Phase PAH Mass Emissions (µg/kWh) for LPP Operation			
Response	**LPP Only - Mode 12**		
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**
Naphthalene	FT-100	822.2	NS
	DF-2	732.5	
	ADMM15	553.7	
	CA	541.6	
	ALS	192.2	
Acenaphthylene	DF-2	55.81	A
	CA	23.13	B
	ALS	11.38	B
	FT-100	10.55	B
	ADMM15	10.25	B
Acenaphthene	DF-2	120.1	NS
	FT-100	98.01	
	CA	94.66	
	ADMM15	78.07	
	ALS	29.89	
Fluorene	DF-2	334.9	A
	CA	219.8	AB
	FT-100	126.6	AB
	ADMM15	118.4	AB
	ALS	59.06	B
Phenanthrene	DF-2	11231	A
	CA	2331	B
	ALS	736.5	B
	FT-100	572.4	B
	ADMM15	459.1	B
Anthracene	DF-2	313.0	A
	CA	66.31	B
	FT-100	46.72	B
	ADMM15	37.82	B
	ALS	25.75	B
Fluoranthene	DF-2	1459.1	A
	CA	375.5	B
	ALS	205.0	B
	FT-100	144.6	B
	ADMM15	98.22	B
Pyrene	DF-2	4002	A
	CA	317.9	B
	ALS	307.0	B
	ADMM15	122.3	B
	FT-100	112.6	B

Table 30. Mode 12 Soluble Phase PAH Mass Emissions (µg/kWh) for LPP Operation (contd)			
Response	**LPP Only - Mode 12**		
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**
Benzo[a]anthracene	DF-2	111.5	A
	CA	26.93	B
	ALS	11.47	B
	FT-100	4.490	B
	ADMM15	2.813	B
Chrysene	DF-2	310.1	A
	CA	57.34	B
	ALS	25.55	B
	FT-100	15.39	B
	ADMM15	8.133	B
Benzo[b]fluoranthene	DF-2	49.24	A
	CA	21.76	B
	ALS	16.87	B
	FT-100	10.49	B
	ADMM15	4.117	B
Benzo[k]fluoranthene	DF-2	35.45	A
	CA	15.26	B
	ALS	12.61	B
	FT-100	8.636	B
	ADMM15	5.015	B
Benzo[e]pyrene	DF-2	33.53	A
	CA	14.12	B
	ALS	10.28	B
	FT-100	9.774	B
	ADMM15	3.537	B
[1]Fuels listed from highest to lowest least squares mean			
[2]Letters designate groups of fuel means within which there are no statistically significant differences			
NS = no statistically significant differences in the mean response at the 5% level of significance			

8.3.5 Phenanthrene

The average phenanthrene for the DF-2 fuel is significantly different than the remaining four fuels. The average phenanthrene for the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

8.3.6 Anthracene

The average anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The average anthracene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.3.7 Fluoranthene

The average fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.3.8 Pyrene

The average pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The average pyrene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.3.9 Benzo[a]anthracene

The average benzo[a]anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[a]anthracene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.3.10 Chrysene

The average chrysene for the DF-2 fuel is significantly different than the remaining four fuels. The average chrysene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.3.11 Benzo[b]fluoranthene

The average benzo[b]fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[b]fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.3.12 Benzo[k]fluoranthene

The average benzo[k]fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[k]fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.3.13 Benzo[e]pyrene

The average benzo[e]pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[e]pyrene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.4 Fuel Impact on Gaseous PAH Species

The gas phase PAH emissions rank the test fuels in the general order shown in Table 31. Included in Table 31 are the least-square means from multifactor ANOVA, along with the statistically significant groupings for the Mode 12 mass emissions. The general trends were for DF-2 to have the highest gas phase PAH emissions, while ADMM15 and FT-100 were always in the statistically lowest grouping. The ANOVA for gas phase PAH species indicated the oxygenated diesel fuel, ADMM15, was statistically equivalent to FT-100 at the Mode 12, idle operating condition.

The discussions to follow are summaries of the multifactor ANOVA performed for each emission response for Mode 12, and refer to the results in Table 31. The ANOVA tables for the Mode 12 analysis can be found in Appendix G.

8.4.1 Naphthalene

There are two distinct fuel groupings with respect to the average naphthalene. The DF-2 and CA fuels are not significantly different from one another but are significantly different from the remaining three fuels. The ALS, ADMM15, and FT-100 fuels are not significantly different from one another, but are significantly different from the remaining two fuels.

8.4.2 2-Methylnaphthalene

There are three distinct fuel groupings with respect to the average 2-methylnaphthalene. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly different from the remaining two fuels. The CA and DF-2 fuels are significantly different from one another and the remaining three fuels.

Table 31. Mode 12 Gaseous Phase PAH Mass Emissions (µg/kWh) for LPP Operation			
Response	**LPP Only - Mode 12**		
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**
Naphthalene	CA	182116	A
	DF-2	130839	A
	ALS	56374	B
	ADMM15	23713	B
	FT-100	6058	B
2-Methylnaphthalene	DF-2	212921	A
	CA	106437	B
	ALS	40671	C
	ADMM15	17201	C
	FT-100	2256	C
1-Methylnaphthalene	DF-2	139827	A
	CA	73642	B
	ALS	21018	C
	ADMM15	8078	C
	FT-100	1429	C
2,6-Dimethylnaphthalene	DF-2	127567	A
	CA	26261	B
	ALS	11261	B
	ADMM15	2048	B
	FT-100	1362	B
Acenaphthylene	DF-2	5591	A
	ALS	2638	B
	CA	1926	B
	ADMM15	953.8	B
	FT-100	888.2	B
Acenaphthene	DF-2	16107	A
	CA	2386	B
	ALS	1707	B
	ADMM15	907.6	B
	FT-100	195.8	B
Fluorene	DF-2	23660	A
	CA	2767	B
	ALS	939.1	B
	FT-100	305.1	B
	ADMM15	296.7	B
Phenanthrene	DF-2	25421	A
	CA	2267	B
	ALS	1891	B
	FT-100	699.8	B
	ADMM15	457.2	B

Table 31. Mode 12 Gaseous Phase PAH Mass Emissions (µg/kWh) for LPP Operation (contd)			
Response	**LPP Only - Mode 12**		
	Fuel	**LS Means[1]**	**Significant Fuel Groups[2]**
Anthracene	DF-2	533.1	A
	CA	129.7	B
	ALS	54.22	B
	FT-100	29.41	B
	ADMM15	22.40	B
Fluoranthene	CA	40.41	NS
	ALS	39.96	
	DF-2	29.95	
	FT-100	27.46	
	ADMM15	14.04	
Pyrene	DF-2	46.40	A
	ALS	39.48	AB
	CA	33.29	AB
	FT-100	21.80	AB
	ADMM15	12.70	B
[1]Fuels listed from highest to lowest least squares mean			
[2]Letters designate groups of fuel means within which there are no statistically significant differences			
NS = no statistically significant differences in the mean response at the 5% level of significance			

8.4.3 1-Methylnaphthalene

There are three distinct fuel groupings with respect to the average 1-methylnaphthalene. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly different from the remaining two fuels. The CA and DF-2 fuels are significantly different from one another and the remaining three fuels.

8.4.4 2,6-Dimethylnaphthalene

The average 2,6-dimethylnaphthalene for the DF-2 fuel is significantly different than the remaining four fuels. The average 2,6-dimethylnaphthalene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.4.5 Acenaphthylene

The average acenaphthylene for the DF-2 fuel is significantly different than the remaining four fuels. The average acenaphthylene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.4.6 Acenaphthene

The average acenaphthene for the DF-2 fuel is significantly different than the remaining four fuels. The average acenaphthene for the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another.

8.4.7 Fluorene

The average fluorene for the DF-2 fuel is significantly different than the remaining four fuels. The average fluorene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.4.8 Phenanthrene

The average phenanthrene for the DF-2 fuel is significantly different than the remaining four fuels. The average phenanthrene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.4.9 Anthracene

The average anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The average anthracene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

8.4.10 Fluoranthene

No statistically significant differences were apparent for the average fluoranthene among the fuels.

8.4.11 Pyrene

The average pyrene for the DF-2 fuel is significantly different than the ADMM15 fuel.

9.0 CONCLUSIONS

The project plan was fully coordinated with DOE and Industry through the Auto/Energy CIDI Ad Hoc Fuels Group. The industrial leaders specified the cylinder balance approach, specified the EGR levels for each of the five speed load conditions, and determined the modal weighting factors for the weighted averages. All fuels were evaluated in triplicate for five modes, with pilot injection off, IMEP of cylinders balanced within 5%, and the Location of Peak Pressure of combustion controlled to 7°ATDC.

Statistically significant (95% confidence) fuel effects on weighted average exhaust emissions were identified for both regulated and unregulated species, including CAA toxic and PAH compounds. The low sulfur fuel containing 15%v/v of the oxygenate dimethoxy methane (ADMM15) or Fischer-Tropsch (FT-100) fuels had the lowest overall weighted average emission response of the test fuels. For unburned hydrocarbons and carbon monoxide, FT-100 had the lowest significant ranking, with ADMM15 and its parent fuel in the next highest rank. DF-2 and pseudo-CARB fuel had the highest regulated emission rankings. For NOx, ADMM15 and FT-100 were not the highest emitters, but were in the second highest significant grouping. The oxygenated low sulfur diesel fuel was statistically the same as Fischer-Tropsch fuel for toxic air pollutants, gaseous and soluble PAH, and PM emissions. Although ADMM15 and FT-100 have statistically similar total PM response, the SOF for the two fuels is statistically different. The ADMM15 fuel has a larger fraction of SOF than the FT-100 fuel, which has the statistically smallest SOF of all test fuels.

For the regulated mass emissions the fuel rank order for the Modal LPP tests (modes 5,6,10,11), with pilot fuel injection off, reflect the results seen for the weighted averages. For HC, CO, and CO_2, the Modal emissions are significantly inversely proportional to BMEP. For NOx, the Modal emissions the results are significantly proportional to BMEP. There are two significant mode groupings for PM, modes 10 and 6 in one group, and modes 11 and 5 in another. There are Fuel * Mode interactions with the regulated emissions. For the CAA toxic compounds, the modal fuel rankings align with the weighted results, with some significant mode groupings. The mode groupings appear inversely proportional to BMEP for the toxic compounds. There are significant Fuel*Mode interactions with each toxic compound. The general trend for the PAH compounds during modal operation reflects the results seen in the weighted average case for fuel rank order.

The general modal effect for both gaseous and soluble PAH emissions were compound specific, and to some effect dependent on BMEP and the molecular weight of the compound.

A pilot fuel injection effect evaluation for all fuels was completed in triplicate for two modes and two pilot fuel injection control strategies. An ANOVA was performed on the pilot fuel injection data along with the same modal data from the non-pilot LPP control strategy. The LPP control with pilot fuel injection turned off was statistically the lowest control strategy for the four toxic air pollutants. The same statistical conclusion could be made for the other particulate PAH compounds. The effect of pilot fuel injection on exhaust emissions, compared to the LPP operation with pilot off, can be summarized as follows:

- PM emissions increase with pilot fuel injection
- NOx emissions decrease with pilot fuel injection
- The ratio of SOF/PM changed with pilot fuel injection condition, and appeared to be a function of the exhaust temperature
- Toxic air pollutant levels increase
- Both soluble and gas phase PAH increase with pilot fuel injection.

The fuel rank order for exhaust emissions with pilot fuel injection operation can be summarized as follows:

- PM rank for ADMM15 and FT-100 lowest, with DF-2 highest
- NOx rank is FT100 lowest, ADMM15 middle, and DF-2 highest
- The SOF of the PM was statistically lowest for FT-100
- Toxic air pollutant rank is FT-100 and ADMM15 lowest, with DF-2 highest
- Both soluble and gas phase PAH rank is FT100 and ADMM15 statistically similar as lowest, with DF-2 the highest emitting fuel.
- Pilot fuel injection changes the magnitude of the emission response, but does not significantly alter the fuel rank order.

Due to the variability of the Mode 12 data, primarily due to engine load control, the idle data was analyzed separately from the other modal data. No statistically significant (95% confidence) fuel effects on exhaust emissions were identified for the regulated species. For the CAA toxic compounds acetaldehyde at mode 12, there were significant fuel effects, with DF-2, ADMM15

and FT-100 being in the highest emitting significant group. For both soluble and gaseous PAH compounds there was either no significant groups or two groups with DF-2 always being in the highest emitting group. The ADMM15 and FT-100 fuels were generally the lowest emitting fuels or were in the lowest emitting group for the PAH compounds at idle.

10.0 RECOMMENDATIONS

The demonstrated effect of the oxygenate compound blended into low sulfur diesel fuel on lowering both regulated and unregulated emissions warrants further investigation. Although the oxygenate utilized in this study, dimethoxy methane, has shown positive emissions benefits, it is a poor choice for commercialization due to volatility characteristics. A parallel oxygenates program[14] has identified two suitable oxygen bearing compounds which warrant investigation as to oxygenate composition effects on toxic or PAH emissions.

There is evidence, Hilden[15] and Figure 121, that suggests oxygen bearing diesel fuels would tolerate further EGR before a smoke limit is reached, thus being beneficial for lowering engine out NOx. The impact on toxic emissions with increased EGR with oxygen bearing fuels warrants investigation.

Another effect of oxygen is the tendency to increase the SOF content of the total particulate matter, which may be beneficial for PM control with an oxidation catalyst. The oxidation of SOF in a catalyst may crack higher molecular weight PAH compounds into smaller ringed components and increased levels of gaseous PAH or toxic emissions. It would be recommended to evaluate the effect of an oxidation catalyst on toxic and PAH emissions.

To meet Tier 2 emission levels, engine out NOx emissions will need to be reduced, which will result in an increase in PM emissions. Thus, the use of a Diesel Particulate Filter (DPF) to meet Tier 2 PM emission levels may be required. However, the DPF will act as a trap that will periodically need regeneration to lower engine backpressure. The DPF may act as a PAH sponge, trapping toxic compounds that could be subject to the effects of thermopherisis. The potential change in gaseous PAH levels due to the accumulation of PM on a DPF warrants investigation.

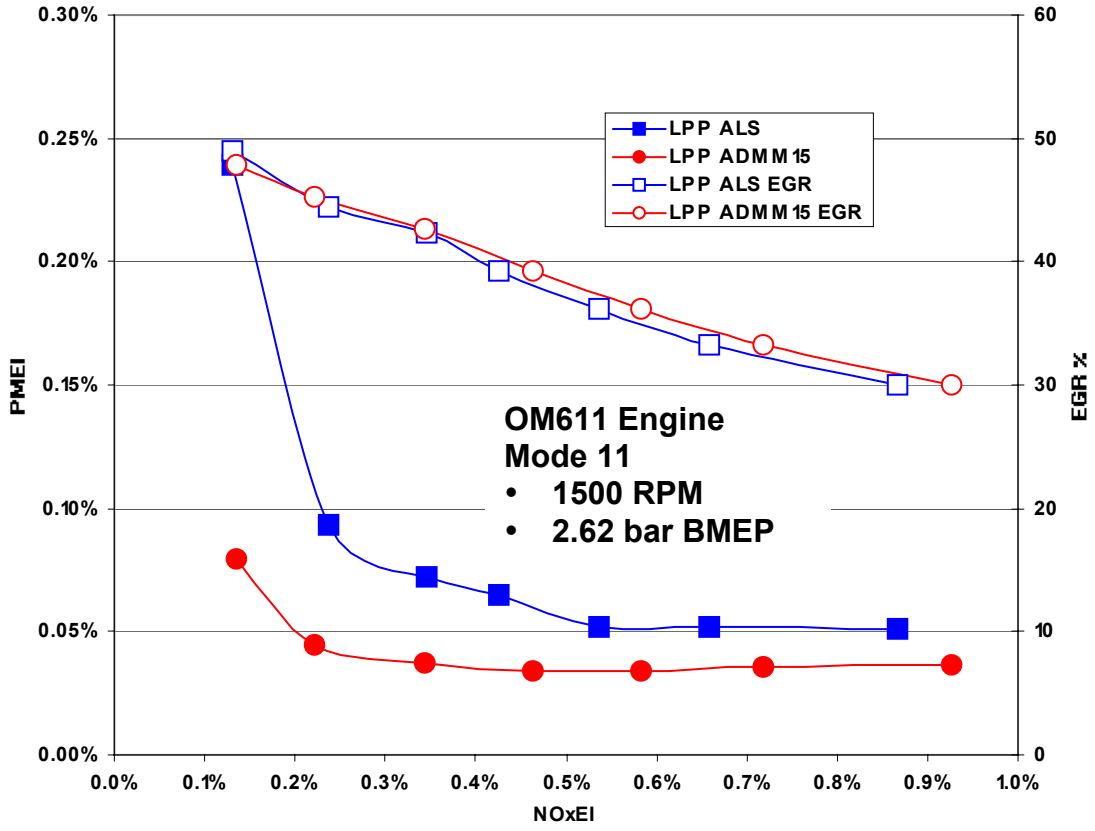


Figure 121. OM611 Engine NOx-PM Emission Index Trade Off with Oxygenated Low Sulfur Diesel Fuel

11.0 REFERENCES

1. Sirman, M.B., Owens, E.C., Whitney, K.A., "Emissions Comparison of Alternative Fuels in an Advanced Automotive Diesel Engine," SAE Paper 2000-01-2048 (2000).

2. Likos, W.E., "Evaluation of Advanced Petroleum-Based Fuels, Interim Report TFLRF No. 356, January 2001.

3. Truax, T.J., and Norbeck, J.M., "Evaluation of Factors that Affect Diesel Exhaust Toxicity," Contract No. 94-312, California Air Resources Board, July 1998.

4. Schramm, J., Foldager, I.,Olsen, N. and Gratz, L., "Emissions from a Diesel Vehicle Operated on Alternative Fuels in Copenhagen," SAE Technical Paper 1999-01-3603, 1999.

5. Westerholm, R., Christensen, A., de Serves,C., Almen, J., “Determination of Polycyclic Aromatic Hydrocarbons (PAH) in Size Fractionated Diesel Particles from a Light Duty Vehicle”, SAE Technical Paper 1999-01-3533, 1999.

6. Kuljukka, T., Savela, K., Peltonen, K., Mikkonen, S., Rantanen, L., “Effect of Fuel Reformulation on Diesel Particulate Emissions-Application of DNA Adduct Test,” SAE Technical Paper 982650, 1998.

7. Collier, A., Jemma, C., Wedekind, B., Hall, D., and Heinze, P., “Sampling and Analysis of Vapor-Phase and Particulate-Bound PAH from Vehicle Exhaust,” SAE Technical Paper 982727, 1998.

8. Tanaka, S., Takizawa, H., Shimizu, T., and Sanse, K., “Effect of Fuel Compositions on PAH in Particulate Matter from DI Diesel Engine,” SAE Technical Paper 982648, 1998.

9. Doel, R. C., “Fuel Property Effects on Polyaromatic Hydrocarbon Emissions from Modern Heavy-Duty Engines,” SAE Technical Paper 964117, 1996.

10. Andrews, G., Ishaq, R., Farrar-Khan, J., Shen. Y., and Williams, P., “The Influence of Speciated Diesel Fuel Composition on Speciated Particulate SOF Emissions,” SAE Technical Paper 980527, 1998.

11. Mason, R.L., Gunst, R.F., and Hess, J.L., Statistical Design and Analysis of Experiments with Applications to Engineering and Science, John Wiley &Sons, Inc, 1989.

12. Milliken, G.A. and Johnson, D.E., Analysis of Messy Data, Volume I: Designed Experiments, Van Nostrand Reinhold, 1984.

13. Szymkowicz, P.G., French, D.T., and Crellin, C.C., "Effects of Advanced Fuels on the Particulate and NOx Emissions from an Optimized Light-Duty CIDI Engine," SAE Paper 2001-01-0148 (2001).

14. Naegeli, D.W., Moulton, S., Owens, E.C., and Frame, E.A., “Oxygenates for Advanced Petroleum-Based Diesel Fuels,” Interim Report No. 357, February 2001.

15. Hilden, D.L., Eckstrom, J.C., and Wolf, L.R., “The Emissions Performance of Oxygenated Diesel Fuels in a Prototype DI Diesel Engine,” SAE paper 2001-01-0650 (2001).

APPENDIX A

Toxic Air Pollutant Sample Procedure

COLLECTION OF ALDEHYDE ON SOLID PHASE DNPH CARTRIDGES AND GASEOUS HYDROCARBONS IN TEDLAR BAGS USING A GAS METERING CART

Leak Check

- Close sampling point valves on tunnel and dilution air box.
- Aldehyde Sampling Cart - Attach the intake and suction lines together without a DNPH cartridge in line.
- Turn on the "Sampling" Switch and observe the digital flow meter. The flow should diminish to at least 0.20 L/min on the number 1 sample counter.
- Open sampling point valves (2 each) on tunnel and (1 each) on dilution air box. Attach 1 Tedlar sample bag each to the ASample≅ pump and the Abackground≅ air pump.
- Attach 1 each labeled DNPH aldehyde cartridge to the “Sample” side and the “background” side of the sampling cart. (Blue coded line for background(1) and Yellow coded line for sample(2)). Flows are regulated so that the sample flow rate is 5 times the background flow rate.

Start of Test:

- In concert with the start of particulate sampling, begin timing the tests (30 min) with a stop watch. At start of test move the "sample" toggle switch 2 clicks upward. Simultaneously turn on the power strip to supply power to the bag sampling pumps.
- (The technician operating the particulate cart will give a “Start” sign.)
- After two minutes turn off the power to the “background” bag sampling pump.
- Sample with the DNPH cartridge and gas “sample” bag for 30 minutes.
- At some time during the test, record the barometric pressure, the LFE intake air temperature, and the ambient air temperatures. (These are displayed on the computer monitor on the test cell console.)

End of Test:

- Move "sample" toggle switch to bottom position.
- Turn off power to the bag sampling pump.
- Record the numbers on both top and bottom digital flow meters.
- Disconnect Sample Bag from Pump.

- Return background pump line switch to the Aon≅ position.
- As soon as practical, deliver the ASample≅ bag to DER GC lab.
- Leave background bag attached until end of test day. (Two minutes for each test.)
- Remove DNPH Sample Cartridge from flow stream cap ends and verify correct label.
- At end of test session, place the aggregate of DNPH cartridges in a zip-lock bag and deliver to DER lab #2 small refrig., under lab bench near vent hood.

REVISION 1

COLLECTION OF ALDEHYDES ON SOLID PHASE DNPH CARTRIDGES AND GASEOUS HYDROCARBONS IN TEDLAR BAGS USING GAS METERING CART

Revision 3/09/00

Due to overloading of some of the aldehyde cartridges,(using up all of the DNPH reagent), the sampling regime was modified as follows:

Zero Time

- Start Aldehyde Cart pumps, (no cartridges installed)
- Start Bag pumps

At 2 minutes

- Stop background bag pump
- Stop Aldehyde cart pumps
- Install cartridges, (sample and background)
- (this 2 minutes purges the sample lines with current sample)

At 3 minutes

- Start aldehyde cart pumps

At 8 minutes

- Close toggle valve to aldehyde “sample” cartridge.
- Read flow totalizer for “sample”
- Remove “sample” cartridge from flow stream
- (5-minute “sample” collection)

At 30 minutes

- Stop aldehyde cartridge pumps
- Stop “sample” bag pump
- Read flow totalizer for Background
- Remove background cartridge from flow stream, (set aside to reinstall 2 minutes into next test)
- Remove “sample bag” and transport to the chem lab for analyses.

APPENDIX B

Fuel Property Analysis

DOE Fuels Analysis 12/23/99			FISCHER-TROPSCH (FT100)	FISCHER-TROPSCH (FT100)	California Reference (CA)	California Reference (CA)	ALTER LOW S (ALS)	ALTER LOW S (ALS)	DMM/ALS BLEND (ADMM15)	DMM/ALS BLEND (ADMM15)	2D CERT (2D)
PROPERTY	UNITS	ASTM	SwRI	Core	SwRI	Core	SwRI	Core	SwRI	Core	SwRI
Density @ 15C	g/ml	D4052	0.7812		0.8378		0.8160		0.8201		0.8426
Distillation		D2887									
IBP	°C		145		145		140		58		
10%	°C		266		192		202		179		
50%	°C		302		251		280		273		
90%	°C		351		325		344		344		
95%	°C		359		339		362		360		
End point	°C		377		372		416		413		
Distillation		D86									
IBP	°C		215	233	189	192	207	210	42	40	183
10%	°C		258	256	215	214	232	232	73	61	216
50%	°C		289	287	255	253	276	275	264	261	260
90%	°C		325	323	309	308	322	321	319	312	309
95%	°C		332	330	321	321	334	334	332	325	325
End Point	°C		337	336	331	331	344	344	342	338	340
Cetane Number		D613	84	87	45	49	63	62	59		44
Cetane Index		D976	78		48		61		57		48
Kinematic Viscosity at 40°C	cSt	D445	3.2	3.1	2.4	2.3	2.9	2.9	1.9	1.7	2.4
Flash Point	°C	D93	98	99	72	70	87	87	<2(D56)	<24	71
Hydrogen	wt%	D5291	15.1		13.4		14.4		13.7		13.0
Carbon	wt%	D5291	84.8		86.4		85.6		81.6		86.7
Oxygen	wt%	difference	0.1		0.2		0.0		4.7		0.3
Nitrogen	µg/g	D4629	7.8		<1.0		<1		<1		60
Sulfur	ppm	D2622	1		176		1		1		337

DOE Fuels Analysis 12/23/99			FISCHER-TROPSCH (FT100)	FISCHER-TROPSCH (FT100)	California Reference (CA)	California Reference (CA)	ALTER LOW S (ALS)	ALTER LOW S (ALS)	DMM/ALS BLEND (ADMM15)	DMM/ALS BLEND (ADMM15)	2D CERT (2D)
PROPERTY	UNITS	ASTM	SwRI	Core	SwRI	Core	SwRI	Core	SwRI	Core	SwRI
Hydrocarbon Type:											
Total Aromatics	wt%	D5186	0.2	<0.1	18.9	18.6	9.0	9.1	8.2*	9	30.3
Mono	wt%	D5186	0.2		15.1		8.5		7.8*		21.4
Poly(Di+Tri)	wt%	D5186	<0.1		3.8		0.5		0.4*		8.9
Parafins	wt%	D2425	97.1		44.2		54.5		54.2*		42.8
Napthenes	wt%	D2425	2.9		37.8		36.9		31.9*		28.8
Water	ppm	D4928	45.0		105.0		77.0		368.0		98.0
Color		D1500	LO.5		L0.5		L0.5		L0.5		1.0
Clear and Bright		D4176	PASS		PASS		PASS		PASS		PASS
Particulates	mg/L	D6217	4.3		<0.01		0.8		0.7**		0.3
Copper Strip Corrosion		D130	1a		1a		1a(50C)		1a		1a
Cloud Point	°C	D2500	-1		-27		-4		-7		-18
Pour Point	°C	D976	-2		-32		-5		-9		-24
Carbon Residue	%	D524	0.071		0.220		0.080		0.038		0.240
Acid Number	mgKOH/g	D664	0.03		0.02		0.02		0.02		0.02
Oxidation Stability		D2274	0.20		0.20		<0.01		0.25***		<0.01
Net Heat of Combustion	MJ/kg	D240	43.9		42.7		43.3		40.8		42.5
Gross Heat of Combustion	MJ/kg	D241		47.2		46.0		46.8		42.0	
Lubricity	mm	D6079	0.59		0.27		0.57		0.49		0.57
BOCLE Scuff	grams	D6078	1900		4300		1600		1950		2850
Detergent	yes/no	unknown									
Sullfur by X-ray Spect	wt%	D4294				0.021					

*The DMM is interfering with these results

**DMM altered shape of filter and may be interfering with results

***Vigorious boiling occurred as sample came to temperature.

APPENDIX C

Pilot Fuel Injection Screening Study

PM Analysis Project: Pilot Fuel Injection Study

Objective

To determine if pilot injection on a direct-injected diesel engine with a Common-Rail fuel system exhibits impacts on engine gaseous and PM exhaust emissions. Ascertain if those impacts may effect the toxicity of the diesel exhaust.

Approach

Operate engine at each of five test modes utilizing three differing control strategies, using CARB fuel. The control approaches consisted of Location of Peak Pressure (LPP) without pilot injection, LPP with Pilot Injection (PILOT A), and the calibrated (PILOT B) engine strategy which also uses pilot injection. The LPP and PILOT A strategies were performed using an RPECS controller. Under RPECS control each cylinder was balanced within 5% of the engine average IMEP. The PILOT B strategy was performed with the OEM controller. The LPP was determined by fixing injection rail pressure, specified EGR, and setting the injector pulse width which met the BMEP setting for the mode. The Main Start of Injection timing was swept and the LPP was noted which produced best torque. When the location of peak pressure during PILOT A operation was determined, the Pilot-to-Main injection pulse width ratio, and the Pilot-to-Main timing gap was kept the same as the Calibrated settings for the mode.

The timings for the differing control strategies are outlined in Table C1 for each of the five test modes. Also shown in Table C1 are the EGR settings for the differing control modes. For the LPP and PILOT A strategies EGR was controlled at levels specified by the Ad Hoc Diesel Fuels committee. The PILOT B strategy controlled to EGR levels mapped by the engine manufacturer. Increased EGR levels are expected to decrease NOx response and increase PM response.

Table C1. Timing Parameters for Pilot Injection Study

			LPP			PILOT B				PILOT A			
Mode	Speed	BMEP, bar	LPP*	MSOI‡	EGR, %	LPP	PSOI†	MSOI	EGR, %	LPP	PSOI	MSOI	EGR, %
12	900	.1	7	5	40	0	9	0	60	5	17	8	40
11	1500	2.62	7	9	30	12	18	2	36	7	24	8	30
10	2000	2	7	12	30	15	23	2	35	7	31	10	30
6	2300	4.2	7	14	15	10	28	4	19	7	38	13	15
5	2600	8.8	7	18	5	8	36	8	13	8	42	14	5

*LPP - Location of Peak Pressure, dATDC
‡MSOI - Main Start of Injection, dBTDC
†PSOI - Pilot Start of Injection, dBTDC

The gaseous and Particulate Matter (PM) emissions were obtained for each test condition. The PM was then analyzed for the percentage of SOF. The hypothesis being major variations in PM and SOF mass emission rates between the control strategies would also result in different PAH levels.

Discussion

Brake Specific Fuel Consumption – The brake specific fuel consumption (BSFC) for the different control strategies for the non-idle modes are shown in Figure C1. The engine was controlled to the same approximate brake output. Fuel consumption variations should reflect relative energy conversion efficiencies. In general the PILOT B control strategy sacrificed fuel

consumption with respect to either of the LPP control approaches. In general, the PILOT A has marginally higher BSFC, most likely due to an advanced initial burn caused by the advanced pilot injection. The idle BSFC shown in Figure C2 shows an improved BSFC for the PILOT B mode. Again the PILOT A has a slightly higher BSFC than the LPP mode. From Table A1, the idle mode (mode 12) has a slightly advanced pressure peak for best torque during PILOT A operation than the LPP mode. The peak pressure location for idle in the PILOT B mode appeared at TDC, however, there was a burn evident later in the cycle around 15° ATDC. For all modes during pilot, the location of peak pressure was not as steady, probably due to the variability of the ignition delay of the pilot injected fuel.

Oxides of Nitrogen – The Oxides of Nitrogen Emission Index (NOxEI) is shown in Figure C3. The NOxEI is the NOx mass emission rate as a percentage of the fuel flow for each mode and control strategy. From Figure C3, it is apparent that either LPP control approach results in higher NOxEI emissions than the PILOT B strategy. The PILOT B strategy appears to concentrate on lower NOxEI, at the expense of efficiency. Also apparent from Figure C3 is that the PILOT A approach reveals lower NOxEI levels than LPP control without pilot injection. The pilot operation has a reduced premixed burn, which may account for the lower NOxEI levels. The differences in EGR levels would also account for some of the NOxEI response seen between the PILOT B, LPP, and PILOT A control strategies. Higher EGR levels tend to result in a lower NOxEI.

Particulate Matter – The Particulate Matter Emission Index (PMEI) data are shown in Figure C4. The PMEI is the PM mass emission rate as a percentage of the fuel flow. As expected due to the NOxEI response, the PMEI levels are higher when pilot injection is utilized. The PILOT B strategy results in a the highest PMEI levels.

For the PM and the Soluble Organic Fraction (SOF) of the PM, specific mass emission rates are shown in Figures C5 and C6 respectively for the non-idle modes. The PM specific emissions are higher for the PILOT A and PILOT B mode of operation. The 2000 RPM/ 2 bar BMEP mode for PILOT B operation may have been influenced by a sample leak, the results do not follow the trends of the other modes. The SOF data in Figure C6 is plotted on the same scale as the PM results, thus relative SOF levels can be ascertained due to the mode of operation. Distinct SOF levels are apparent between the control strategies and each operating modes. Overall pilot injection appears to increase PM but reduce the level of SOF.

For the PM, and the Soluble Organic Fraction (SOF) of the PM, specific mass emission rates are shown in Figures C7 for the idle mode. The PM emission for the idle mode is higher for the PILOT B and PILOT A operation compared to LPP. The SOF is in similar proportions for the LPP and PILOT B modes of operation at idle.

Combustion – Cylinder pressure histories were recorded for each test mode and control strategy. Figure C8 is the cylinder pressure histories from cylinder #1 for Mode 11, 1500 RPM and 2.62 bar BMEP. From the pressure histories, it is evident the rate of pressure rise is lower when pilot operation is utilized. This is evident in the audible noise during engine operation.

The apparent heat release rates were calculated and are shown in Figure C9 for each control strategy. The relative timings of the pilot and main injection events are shown on the heat release curves. From the heat release traces the early burn is evident for the cases where pilot injection is utilized, PILOT B and PILOT A. Combustion occurs before TDC with pilot injection. Due to the very advanced injection in the PILOT A control mode, combustion appears to initiate around

8 degrees before TDC. Combustion initiates during PILOT B operation at around 6 degrees before TDC.

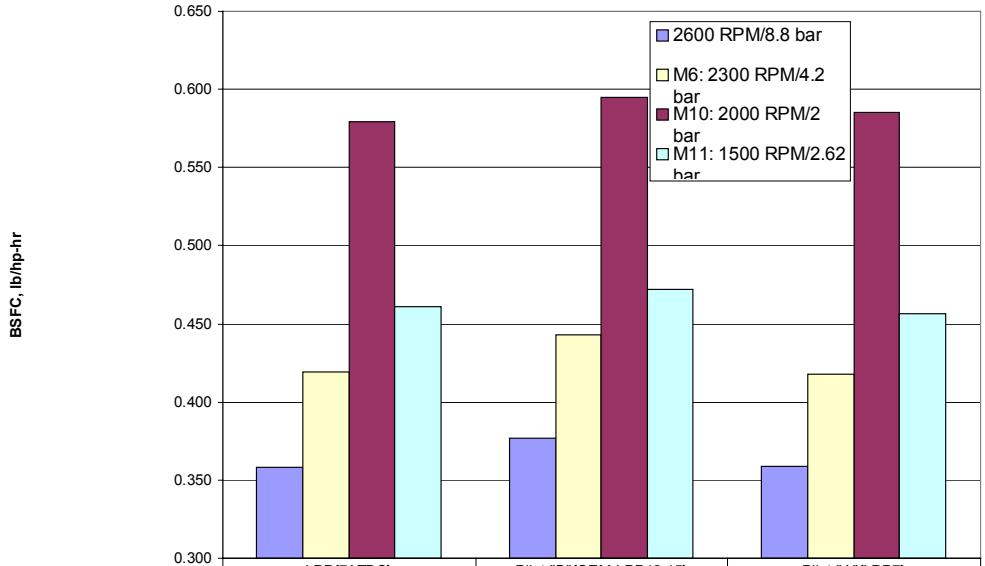
High initial combustion rates would be expected to correlate with NOx formation. The NOxEI data ranks the control strategies as would be expected from the burn rates. The magnitude of the tail of the burn curve would be expected to suggest relative PM levels. The PMEI data ranks with the relative magnitude of the tail of the burn curves for the three control strategies.

The shape and phasing of the burn curves suggest the timing of the pilot injection for the PILOT A control strategy may be to far advanced. The pilot-to-main injection gap utilized under PILOT B operation was maintained for the PILOT A operation. A timing sweep study was performed to evaluate the effect of the Pilot-toMain Gap (PMGap) on BSFC, NOx, and Bosch Smoke Number (BSN). The sweeps were performed at mode 11, 1500 RPM/2.62 bar BMEP. The typical PILOT B values for this mode are a PMGap of 1.8 ms with a MSOI of 2 DBTDC. The MSOI utilized for LPP control is 8 DBTDC. The PMGap and MSOI for the PILOT A strategy was 1.8 ms and 8 DBTDC respectively. The range of PMGap was chosen by fixing injection quantity, and looking for a change in the torque response at different PMGaps. PMGaps longer than 1.8 ms and shorter than 1.4 ms resulted in large torque decreases. The sweeps were performed with constant injection pulse widths.

The data in Figure C10 represents one reading for BSFC at each PMGap and MSOI timing. As seen in Figure C11, a PMGap of 1.6 ms resulted in the most efficient operation, at all MSOI timings.

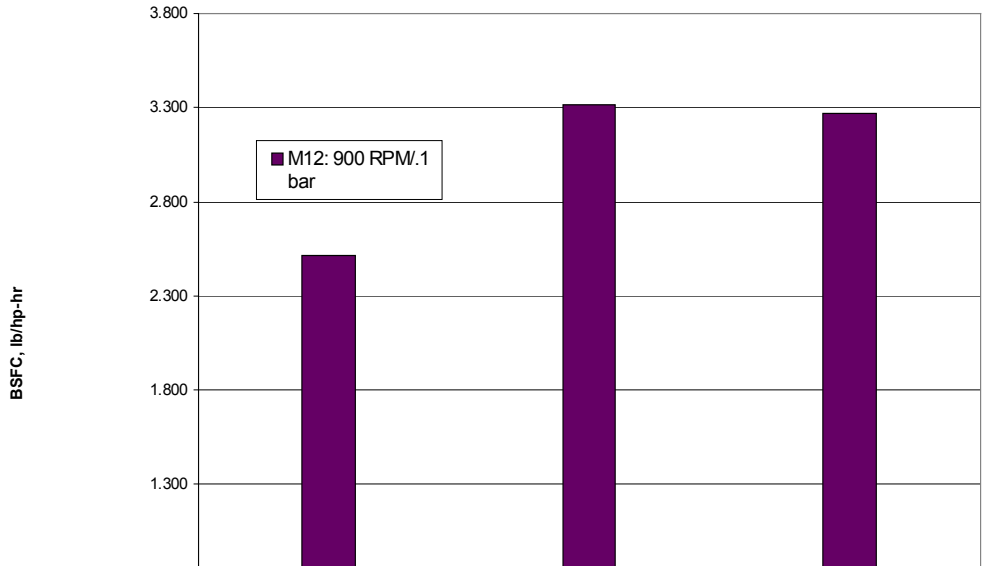
The NOx response shown in Figure C11 indicate MSOI timing is more critical than PMGap. As MSOI timing is advanced, NOx increases. The PMGap at 1.6 ms had the highest NOx response at each MSOI timing. Considering the efficiency improvement seen at 1.6ms PMGap, the higher NOx response is not unexpected.

The variations in BSN for the timing sweeps shown in Figure C12 were not expected. The BSN decreases with advanced MSOI, which coincides with PM-NOx tradeoff, and the NOx response. What was not anticipated was the smoke number relationship with respect to PMGap. The PMGap for the highest efficiency has the highest smoke levels, and as seen from Figure C12 the highest NOx.



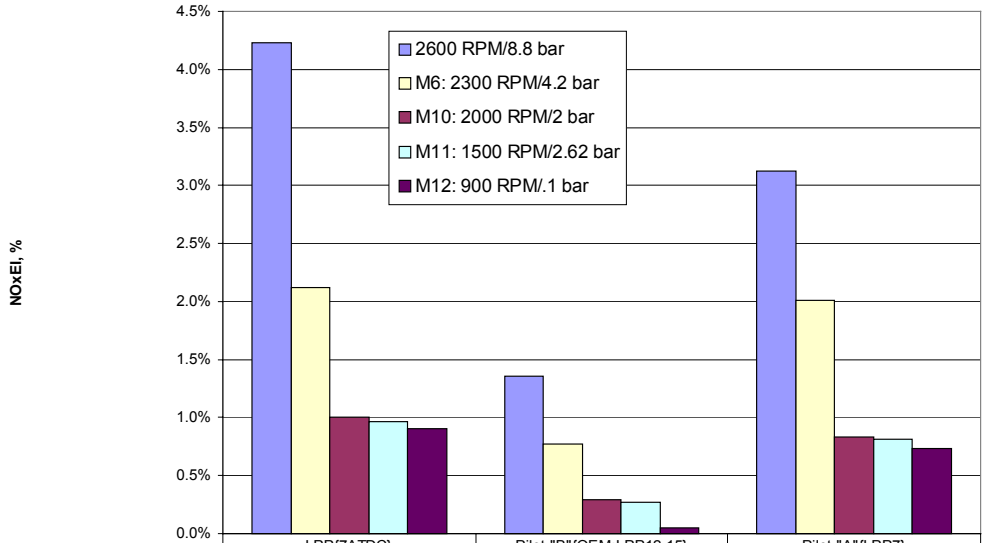
	LPP{7ATDC}	Pilot "B"{OEM:LPP12-15}	Pilot "A"{LPP7}
2600 RPM/8.8 bar	0.358	0.377	0.359
M6: 2300 RPM/4.2 bar	0.419	0.443	0.418
M10: 2000 RPM/2 bar	0.579	0.595	0.585
M11: 1500 RPM/2.62 bar	0.461	0.472	0.457

Figure C1. Brake Specific Fuel Consumption as a Function of Control Strategy



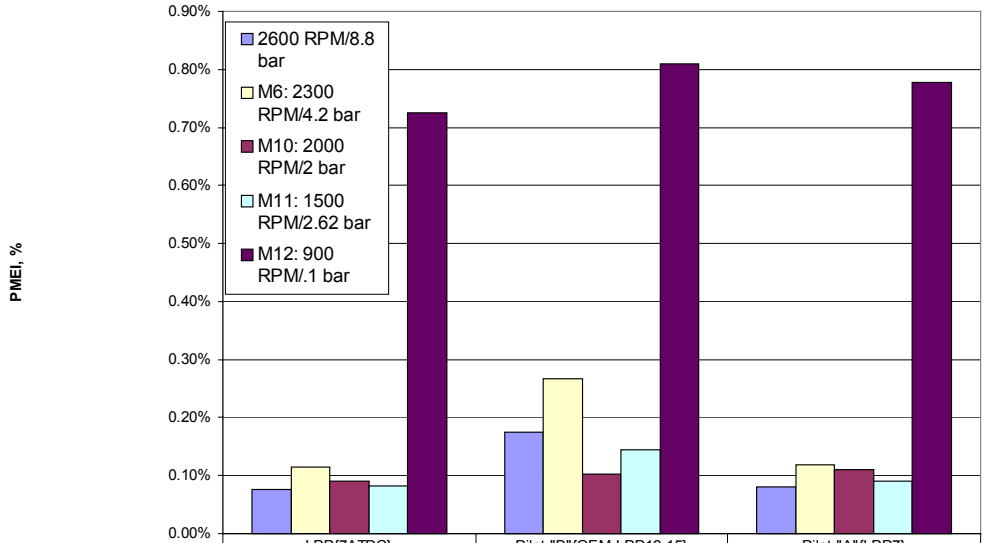
	LPP{7ATDC}	Pilot "B"{OEM:LPP12-15}	Pilot "A"{LPP7}
M12: 900 RPM/.1 bar	2.512	3.317	3.268

Figure C2. Idle Mode BSFC as a Function of Control Strategy



	LPP{7ATDC}	Pilot "B"{OEM:LPP12-15}	Pilot "A"{LPP7}
2600 RPM/8.8 bar	4.232%	1.354%	3.125%
M6: 2300 RPM/4.2 bar	2.123%	0.775%	2.004%
M10: 2000 RPM/2 bar	1.004%	0.292%	0.832%
M11: 1500 RPM/2.62 bar	0.960%	0.271%	0.810%
M12: 900 RPM/.1 bar	0.906%	0.053%	0.735%

Figure C3. Oxides of Nitrogen Emission Index as a Function of Control Strategy



	LPP{7ATDC}	Pilot "B"{OEM:LPP12-15}	Pilot "A"{LPP7}
2600 RPM/8.8 bar	0.077%	0.174%	0.080%
M6: 2300 RPM/4.2 bar	0.115%	0.268%	0.119%
M10: 2000 RPM/2 bar	0.091%	0.102%	0.111%
M11: 1500 RPM/2.62 bar	0.083%	0.145%	0.091%
M12: 900 RPM/.1 bar	0.726%	0.811%	0.777%

Figure C4. Particulate Matter Emission Index as a Function of Control Strategy

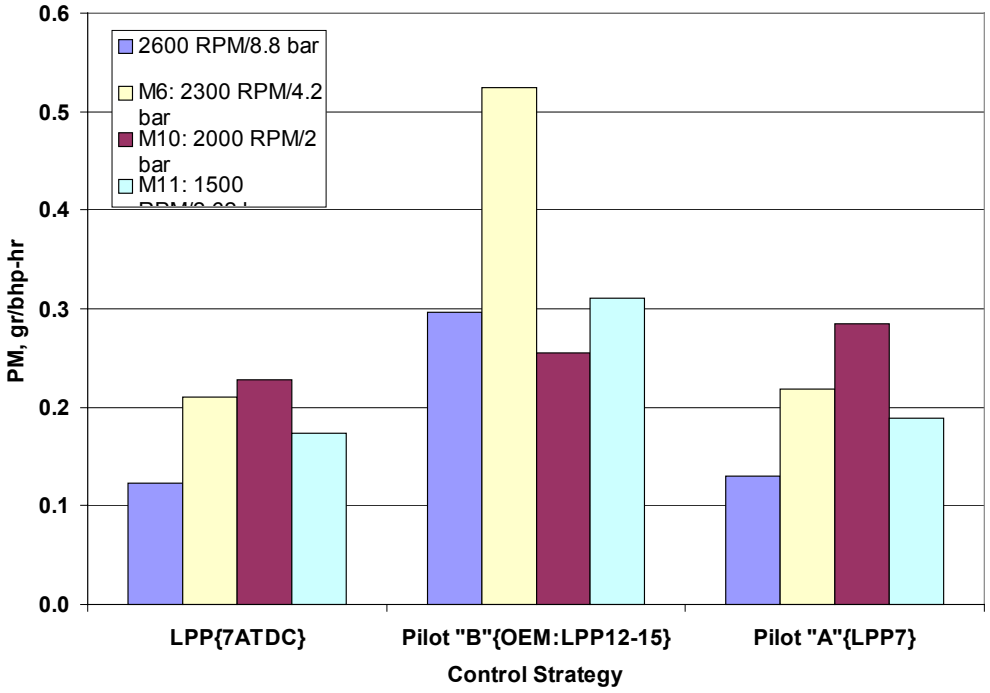


Figure C5. PM Specific Mass Emission Rates

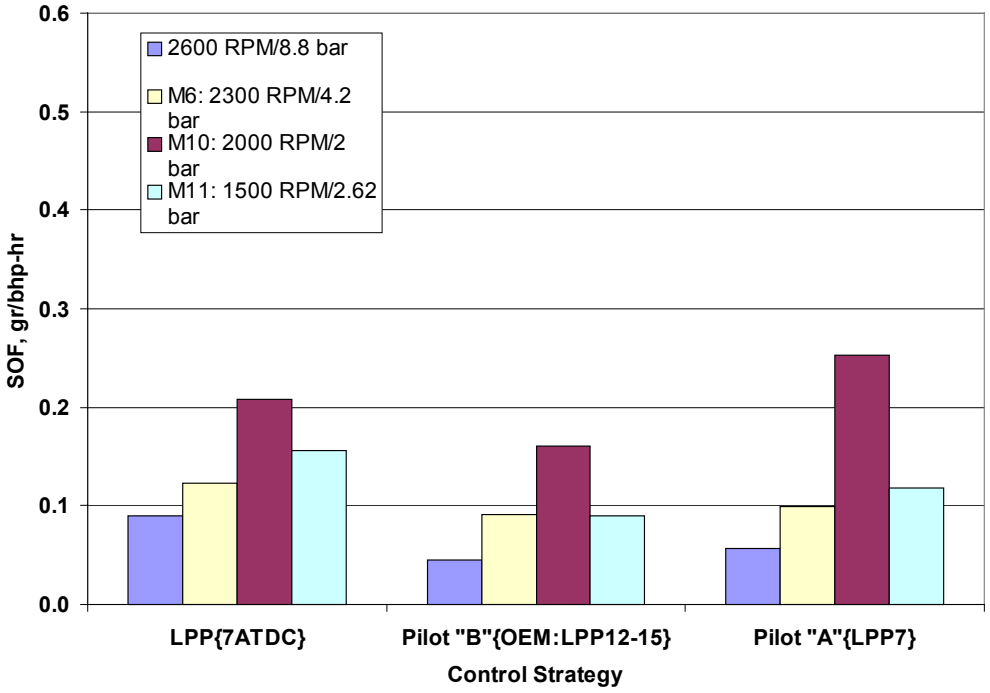


Figure C6. Soluble Organic Fraction Specific Mass Emission Rates

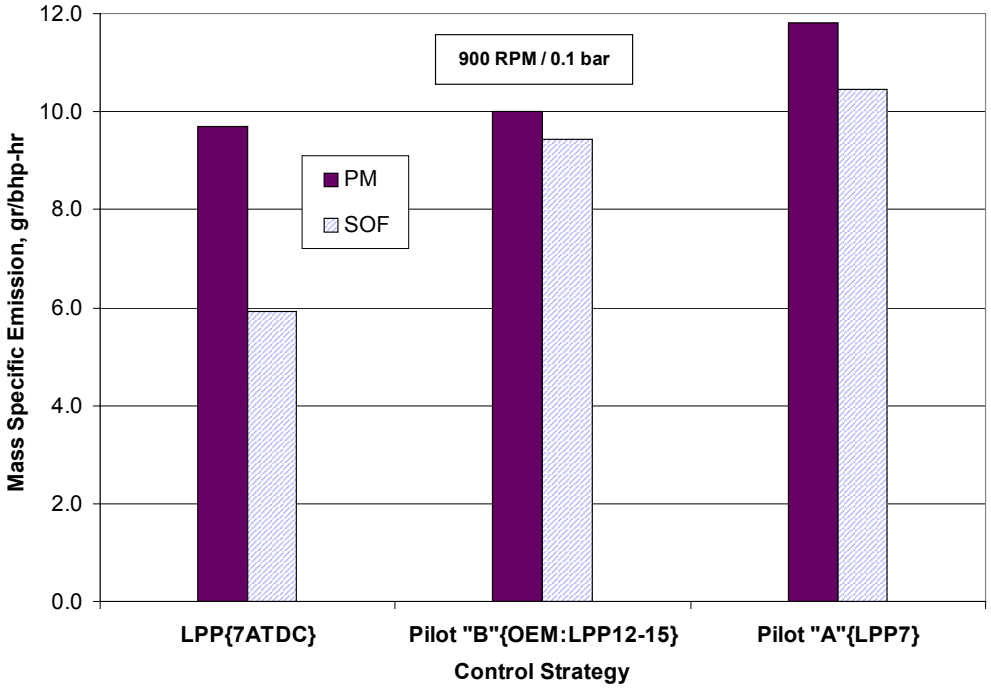


Figure C7. Idle Mode PM Specific Mass Emission Rates

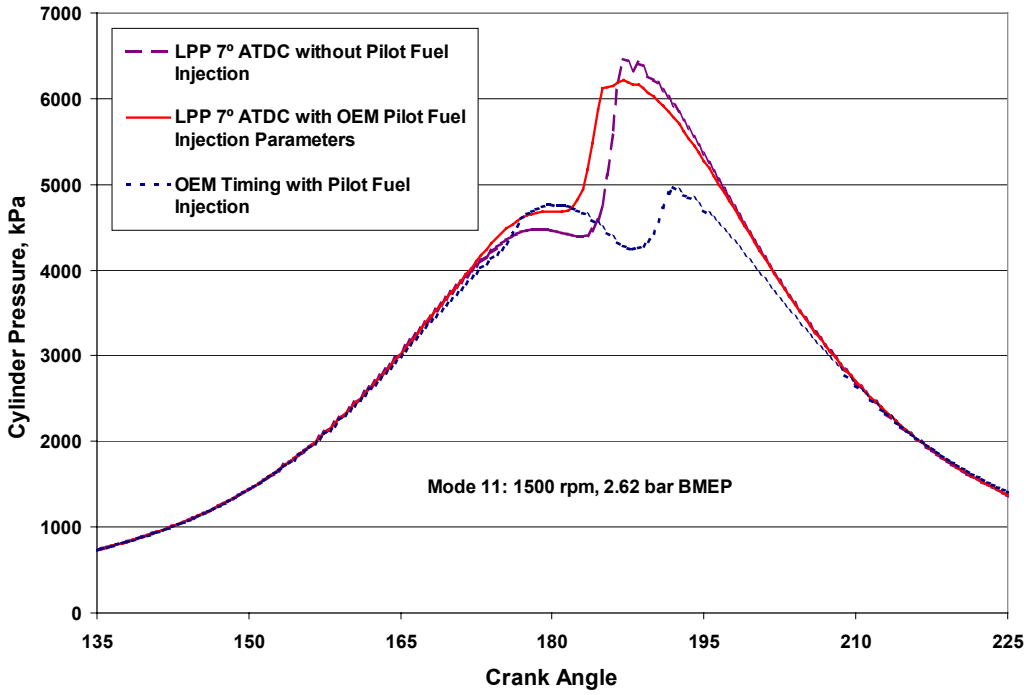


Figure C8. Cylinder Pressure Histories as a Function of Control Strategy

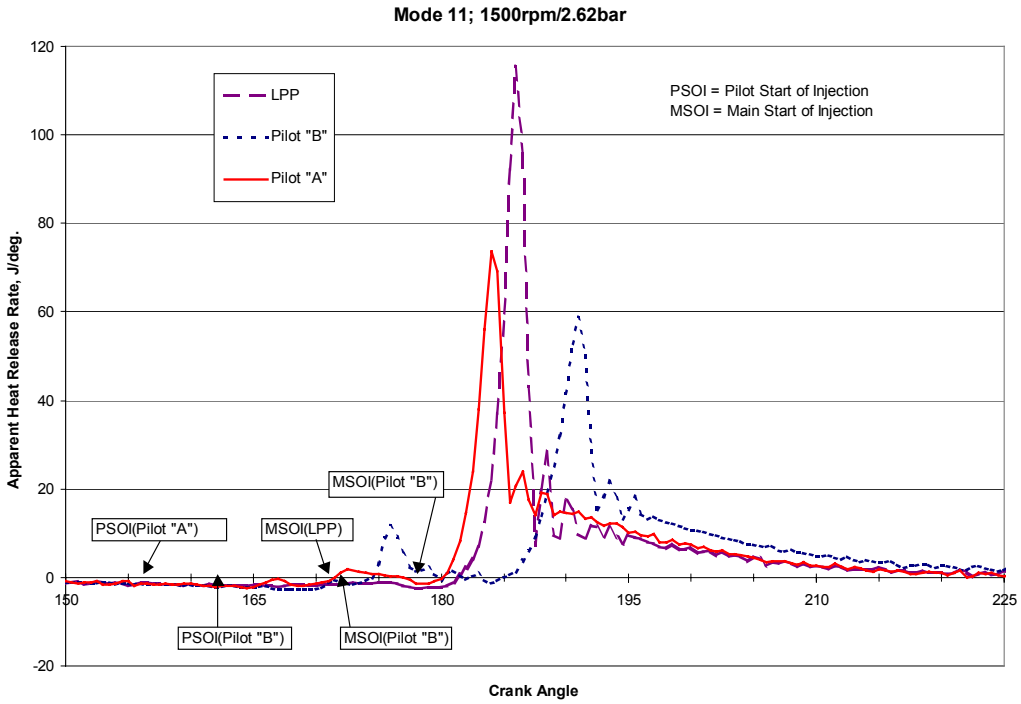


Figure C9. Heat Release Rates as a Function of Control Strategy

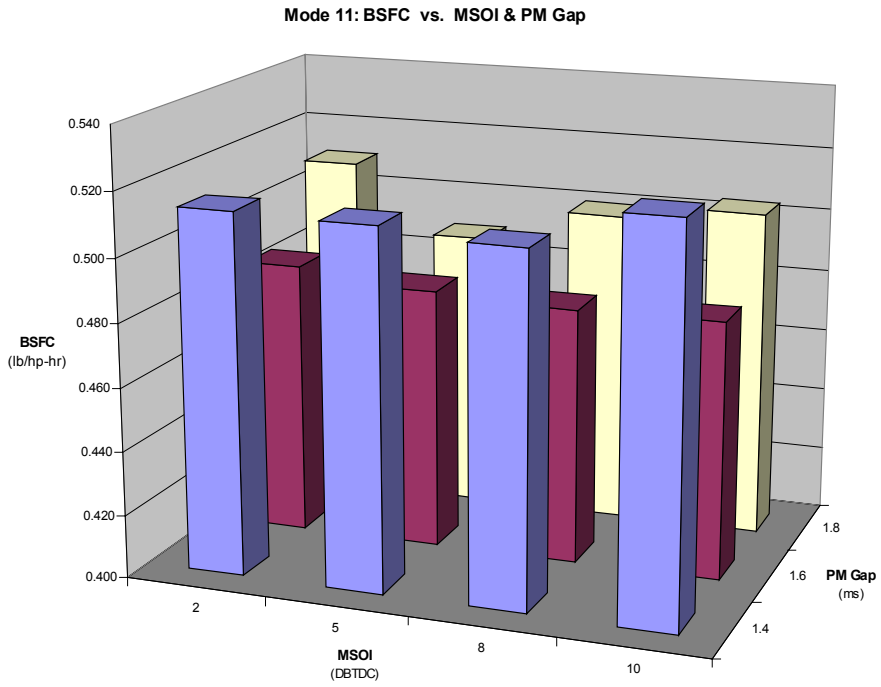


Figure C10. Brake Specific Fuel Consumption for Mode 11 Timing Sweeps

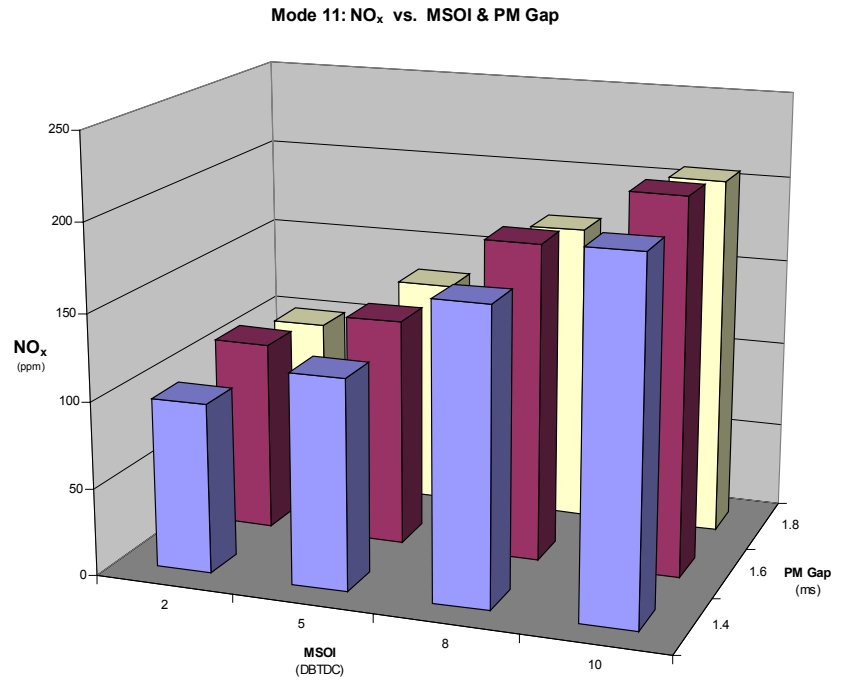


Figure C11. Oxides on Nitrogen for Mode 11 Timing Sweeps

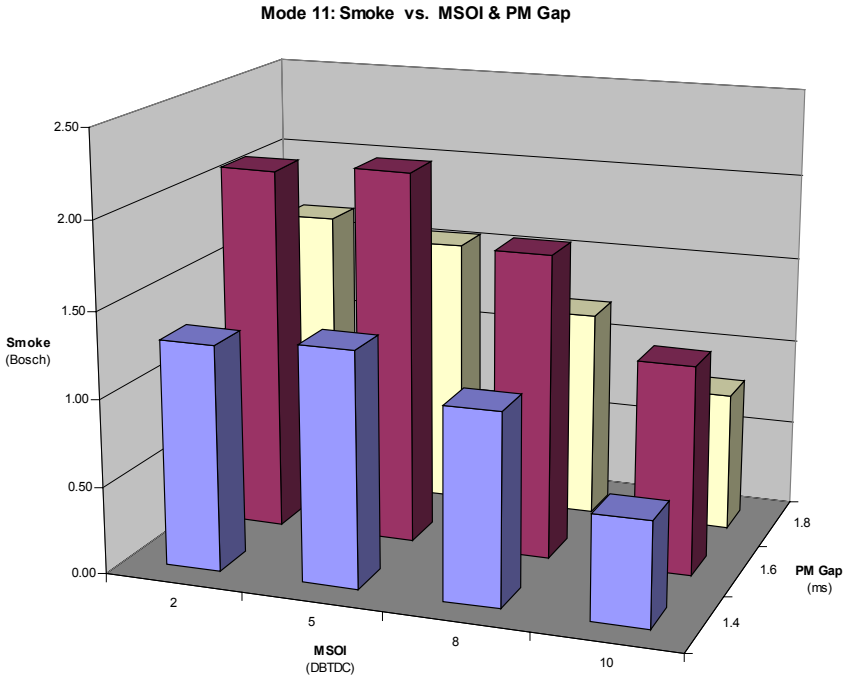


Figure C12. Bosch Smoke Number for Mode 11 Timing Sweeps

APPENDIX D

ANOVA for Weighted Averages

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1,3 Butadiene Toxic Gaseous Emissions D-17
Formaldehyde Toxic Gaseous Emissions D-19
Acetaldehyde Toxic Gaseous Emissions D-21
Naphthalene Gaseous PAH D-23
2-Methylnaphthalene Gaseous PAH D-25
1-Methylnaphthalene Gaseous PAH D-27
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Acenaphthylene Gaseous PAH D-31
Acenaphthene Gaseous PAH D-33
Fluorene Gaseous PAH D-35
Phenanthrene Gaseous PAH D-37
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Naphthalene Soluble PAH D-45
Acenaphthylene Soluble PAH D-47
Acenaphthene Soluble PAH D-49
Fluorene Soluble PAH D-51
Phenanthrene Soluble PAH D-53
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Fluoranthene Soluble PAH D-57
Pyrene Soluble PAH D-59
Benzo[a]anthracene D-61
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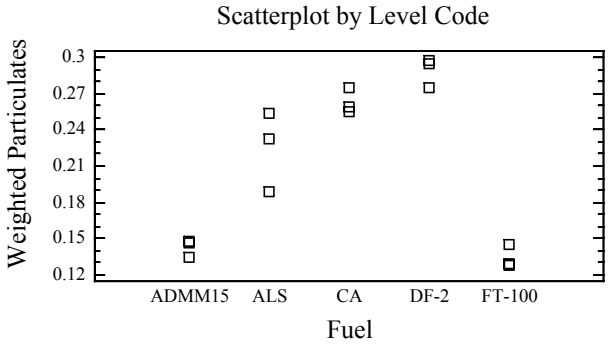
Multifactor ANOVA - Total Particulates (g/kW-hr)
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wpm
Factors:
fuel

Number of complete cases: 15

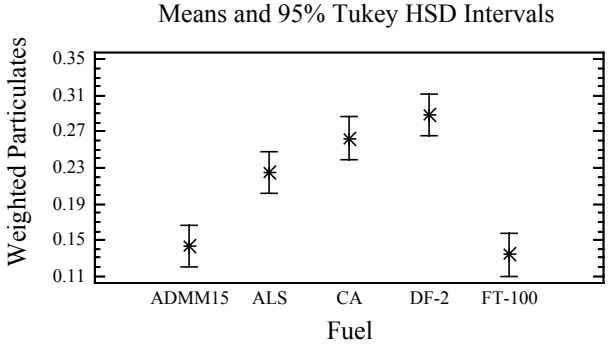


Analysis of Variance for wpm - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.0584894	4	0.0146223	48.38	0.0000
RESIDUAL	0.00302259	10	0.000302259		
TOTAL (CORRECTED)	0.061512	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted particulates among the fuels.



CONCLUSION: Average particulate at fuels FT-100 and ADMM15 are not significantly different from one another, but are different than the other three fuels. The average particulate at Fuel ALS is significantly different than Fuel DF-2. The CA fuel is not significantly different than either the ALS or DF-2 fuel.

Multiple Range Tests for wpm by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	0.133692	X
ADMM15	3	0.143126	X
ALS	3	0.224882	X
CA	3	0.262719	XX
DF-2	3	0.288757	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.0817558	0.0467219
ADMM15 - CA	*-0.119593	0.0467219
ADMM15 - DF-2	*-0.145631	0.0467219
ADMM15 - FT-100	0.00943372	0.0467219
ALS - CA	-0.0378373	0.0467219
ALS - DF-2	*-0.0638755	0.0467219
ALS - FT-100	*0.0911895	0.0467219
CA - DF-2	-0.0260382	0.0467219
CA - FT-100	*0.129027	0.0467219
DF-2 - FT-100	*0.155065	0.0467219

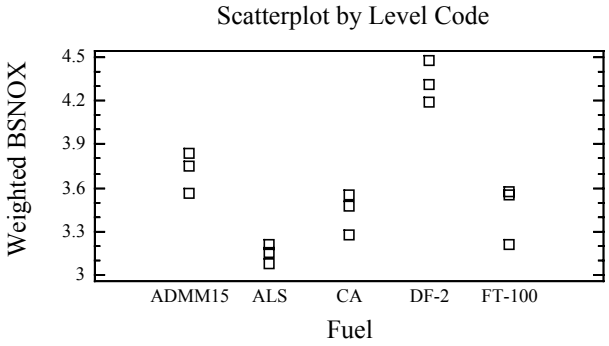
* denotes a statistically significant difference.

Multifactor ANOVA - BSNOX (g/Kw-hr)
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbsnox
Factors:
fuel

Number of complete cases: 15

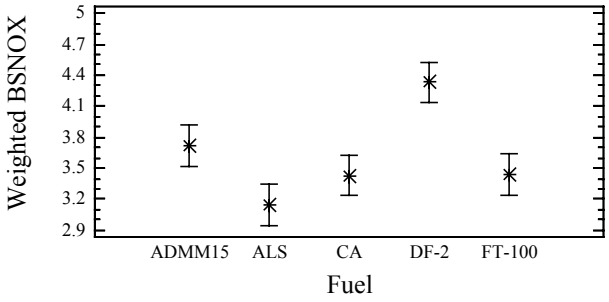


Analysis of Variance for wbsnox - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	2.42468	4	0.60617	27.97	0.0000
RESIDUAL	0.21674	10	0.021674		
TOTAL (CORRECTED)	2.64142	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted BSNOX among the fuels.



CONCLUSION: The average weighted BSNOX for the DF-2 fuel is significantly different from the remaining for fuels. The other finding is the average weighted BSNOX for the ADMM15 fuel is significantly different than the ALS fuel.

Multiple Range Tests for wbsnox by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

ALS	3	3.14535	X
CA	3	3.43069	XX
FT-100	3	3.4413	XX
ADMM15	3	3.71901	X
DF-2	3	4.33103	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*0.573659	0.39564
ADMM15 - CA	0.28832	0.39564
ADMM15 - DF-2	*-0.612027	0.39564
ADMM15 - FT-100	0.277703	0.39564
ALS - CA	-0.28534	0.39564
ALS - DF-2	*-1.18569	0.39564
ALS - FT-100	-0.295956	0.39564
CA - DF-2	*-0.900347	0.39564
CA - FT-100	-0.0106164	0.39564
DF-2 - FT-100	*0.889731	0.39564

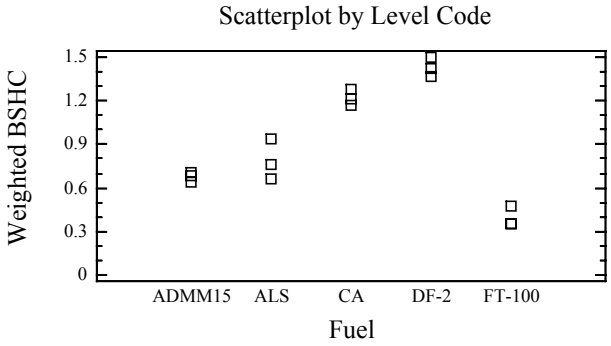
* denotes a statistically significant difference.

Multifactor ANOVA - BSHC (g/kW-hr)
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbshc
Factors:
fuel

Number of complete cases: 15

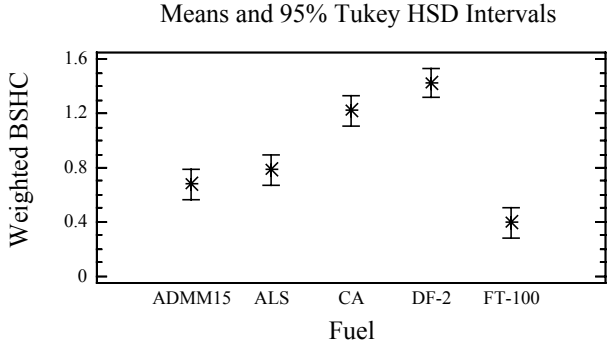


Analysis of Variance for wbshc - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	2.10344	4	0.52586	79.11	0.0000
RESIDUAL	0.0664694	10	0.00664694		
TOTAL (CORRECTED)	2.16991	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted BSHC among the fuels.



CONCLUSION: The average weighted BSHC for the FT-100 fuel is significantly different from the remaining four fuels. The other fuels can be divided into two distinct fuel groupings. The ADMM15 and ALS fuels are not significantly different from one another, but are different from the CA and DF-2 fuels. The CA and DF-2 fuels are not significantly
different from one another.

Multiple Range Tests for wbshc by fuel

```
------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
fuel           Count     LS Mean           Homogeneous Groups
------------------------------------------------------------------------------
FT-100         3         0.39346           X
ADMM15         3         0.676601           X
ALS            3         0.784842           X
CA             3         1.22085             X
DF-2           3         1.42769             X
------------------------------------------------------------------------------
Contrast                                 Difference           +/-  Limits
------------------------------------------------------------------------------
ADMM15 - ALS                              -0.108241           0.2191
ADMM15 - CA                              *-0.54425            0.2191
ADMM15 - DF-2                            *-0.751084           0.2191
ADMM15 - FT-100                          *0.283142            0.2191
ALS - CA                                 *-0.436009           0.2191
ALS - DF-2                               *-0.642843           0.2191
ALS - FT-100                             *0.391383            0.2191
CA - DF-2                                 -0.206834           0.2191
CA - FT-100                              *0.827392            0.2191
DF-2 - FT-100                            *1.03423             0.2191
------------------------------------------------------------------------------
* denotes a statistically significant difference.
```

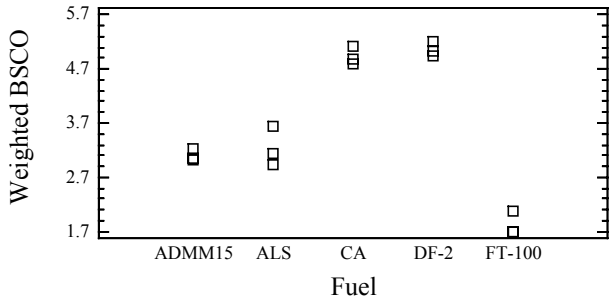
Multifactor ANOVA - BSCO (g/kW-hr)
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbsco
Factors:
fuel

Number of complete cases: 15

Scatterplot by Level Code



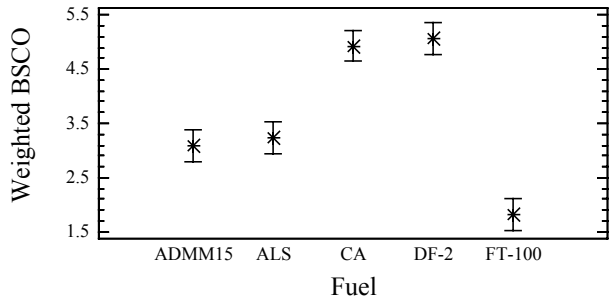
Analysis of Variance for wbsco - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	22.2863	4	5.57158	116.78	0.0000
RESIDUAL	0.477119	10	0.0477119		
TOTAL (CORRECTED)	22.7635	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted BSCO among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average weighted BSCO for the FT-100 fuel is significantly different from the remaining four fuels. The other fuels can be dividied into two distinct fuel groupings. The ADMM15 and the ALS fuels are not significantly different from one another,
but are different from the CA and DF-2 fuels. The CA and DF-2 fuels are not significantly
different from one another.

Multiple Range Tests for wbsco by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	1.82976	X
ADMM15	3	3.0948	X
ALS	3	3.23579	X
CA	3	4.93057	X
DF-2	3	5.06338	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.140994	0.587008
ADMM15 - CA	*-1.83578	0.587008
ADMM15 - DF-2	*-1.96858	0.587008
ADMM15 - FT-100	*1.26504	0.587008
ALS - CA	*-1.69478	0.587008
ALS - DF-2	*-1.82759	0.587008
ALS - FT-100	*1.40603	0.587008
CA - DF-2	-0.132808	0.587008
CA - FT-100	*3.10082	0.587008
DF-2 - FT-100	*3.23362	0.587008

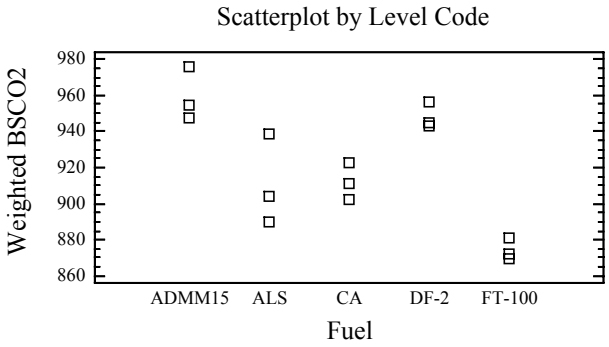
* denotes a statistically significant difference.

Multifactor ANOVA - BSCO2 (g/kW-hr)
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbsco2
Factors:
fuel

Number of complete cases: 15

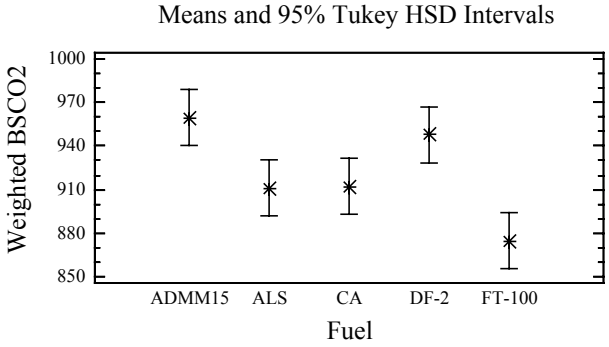


Analysis of Variance for wbsco2 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	13720.5	4	3430.12	16.43	0.0002
RESIDUAL	2087.39	10	208.739		
TOTAL (CORRECTED)	15807.9	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted BSCO2 among the fuels.



CONCLUSION: The average weighted BSCO2 for the ADMM15 fuel is significantly different than the ALS, CA, and FT-100 fuels. Also, the average weighted BSCO2 for the FT-100 fuel is significantly different than the DF-2 fuel.

Multiple Range Tests for wbsco2 by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	874.221	X
ALS	3	910.932	XX
CA	3	911.941	XX
DF-2	3	947.978	XX
ADMM15	3	959.394	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*48.4621	38.8269
ADMM15 - CA	*47.4526	38.8269
ADMM15 - DF-2	11.4164	38.8269
ADMM15 - FT-100	*85.1726	38.8269
ALS - CA	-1.00949	38.8269
ALS - DF-2	-37.0457	38.8269
ALS - FT-100	36.7105	38.8269
CA - DF-2	-36.0362	38.8269
CA - FT-100	37.72	38.8269
DF-2 - FT-100	*73.7562	38.8269

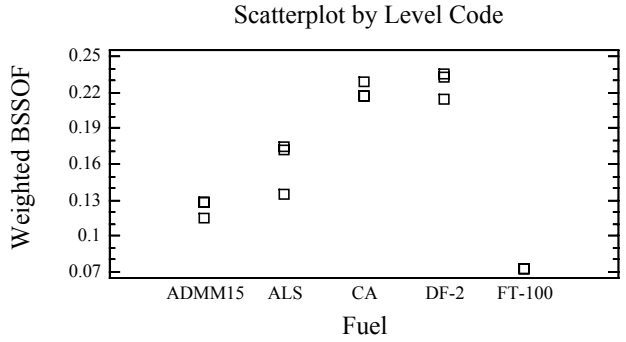
* denotes a statistically significant difference.

Multifactor ANOVA - BSSOF (g/kW-hr)
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbssof
Factors:
fuel

Number of complete cases: 14

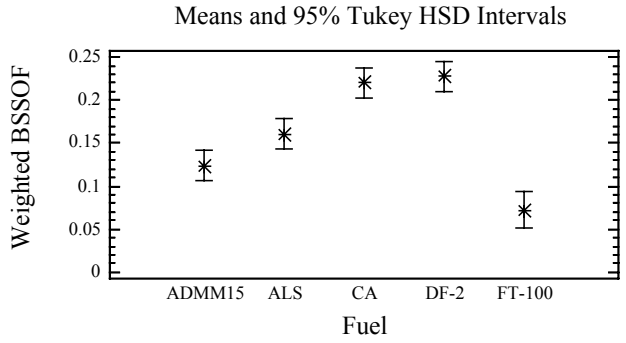


Analysis of Variance for wbssof - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.0434396	4	0.0108599	65.70	0.0000
RESIDUAL	0.00148772	9	0.000165303		
TOTAL (CORRECTED)	0.0449273	13			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted BSSOF among the fuels.



CONCLUSION: There are four distinct fuel groupings with respect to the average weighted BSSOF. The FT-100, ADMM15, and ALS fuels are significantly different from one another and the remaining two fuels. The CA and DF-2 fuels are not significantly different from one another, but are significantly different from the other three fuels.

Multiple Range Tests for wbssof by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	2	0.0722652	X
ADMM15	3	0.123734	X
ALS	3	0.160837	X
CA	3	0.220703	X
DF-2	3	0.227858	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.0371037	0.0352706
ADMM15 - CA	*-0.096969	0.0352706
ADMM15 - DF-2	*-0.104124	0.0352706
ADMM15 - FT-100	*0.0514686	0.0394337
ALS - CA	*-0.0598653	0.0352706
ALS - DF-2	*-0.0670201	0.0352706
ALS - FT-100	*0.0885723	0.0394337
CA - DF-2	-0.00715478	0.0352706
CA - FT-100	*0.148438	0.0394337
DF-2 - FT-100	*0.155592	0.0394337

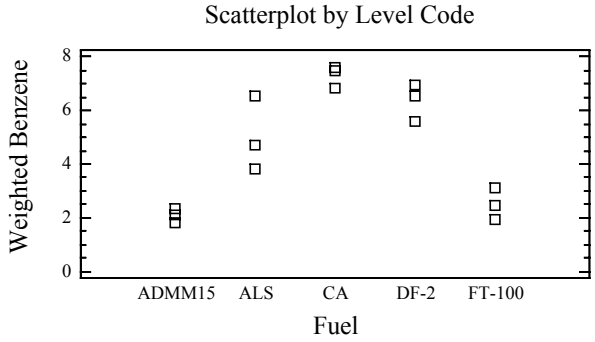
* denotes a statistically significant difference.

Multifactor ANOVA - Benzene (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbenz
Factors:
fuel

Number of complete cases: 15

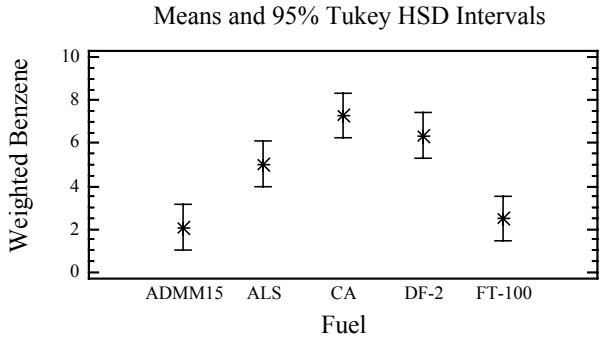


Analysis of Variance for wbenz - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	63.8974	4	15.9744	25.90	0.0000
RESIDUAL	6.16766	10	0.616766		
TOTAL (CORRECTED)	70.0651	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted benzene among the fuels.



CONCLUSION: Average weighted benzene at fuels ADMM15 and FT-100 are not significantly different from one another, but are different than the other three fuels. The average weighted benzene at fuel ALS is significantly different than fuel CA. The DF-2 fuel is not significantly different than either the ALS or CA fuel.

Multiple Range Tests for wbenz by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	2.07455	X
FT-100	3	2.50431	X
ALS	3	5.01701	X
DF-2	3	6.35954	XX
CA	3	7.29669	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-2.94246	2.11053
ADMM15 - CA	*-5.22215	2.11053
ADMM15 - DF-2	*-4.28499	2.11053
ADMM15 - FT-100	-0.429765	2.11053
ALS - CA	*-2.27968	2.11053
ALS - DF-2	-1.34253	2.11053
ALS - FT-100	*2.5127	2.11053
CA - DF-2	0.937154	2.11053
CA - FT-100	*4.79238	2.11053
DF-2 - FT-100	*3.85523	2.11053

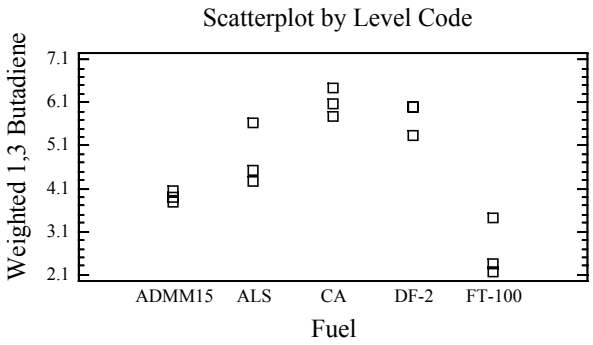
* denotes a statistically significant difference.

Multifactor ANOVA - 1,3 Butadiene (mg/Kw-hr) Toxic Gaseous Emissions
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbutad
Factors:
fuel

Number of complete cases: 15

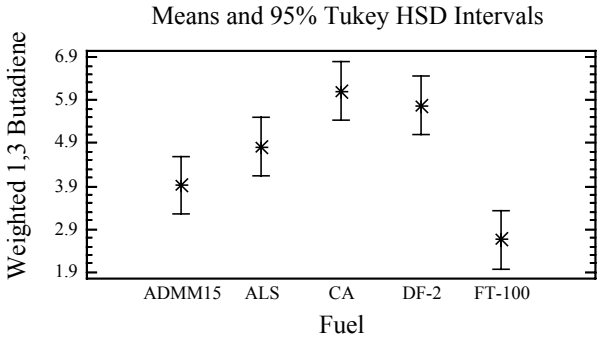


Analysis of Variance for wbutad - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	23.8799	4	5.96997	23.71	0.0000
RESIDUAL	2.51827	10	0.251827		
TOTAL (CORRECTED)	26.3981	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted 1,3 butadiene among the fuels.



CONCLUSION: The average weighted 1,3 butadiene for the CA and DF-2 fuels are not significantly different from one another, but are sigificantly different than the ADMM15 and FT-100 fuels. The ADMM15 and FT-100 fuels are not significantly different from one another. Also, the average weighted 1,3 butadiene for the ALS fuel is significantly different than the FT-100 fuel.

Multiple Range Tests for wbutad by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	2.64965	X
ADMM15	3	3.921	XX
ALS	3	4.81705	XX
DF-2	3	5.77838	X
CA	3	6.10812	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.896042	1.3486
ADMM15 - CA	*-2.18711	1.3486
ADMM15 - DF-2	*-1.85738	1.3486
ADMM15 - FT-100	1.27135	1.3486
ALS - CA	-1.29107	1.3486
ALS - DF-2	-0.961334	1.3486
ALS - FT-100	*2.16739	1.3486
CA - DF-2	0.329738	1.3486
CA - FT-100	*3.45846	1.3486
DF-2 - FT-100	*3.12873	1.3486

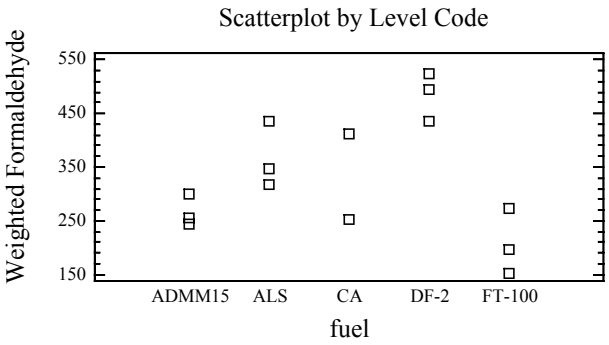
* denotes a statistically significant difference.

Multifactor ANOVA - Formaldehyde (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wform
Factors:
fuel

Number of complete cases: 14

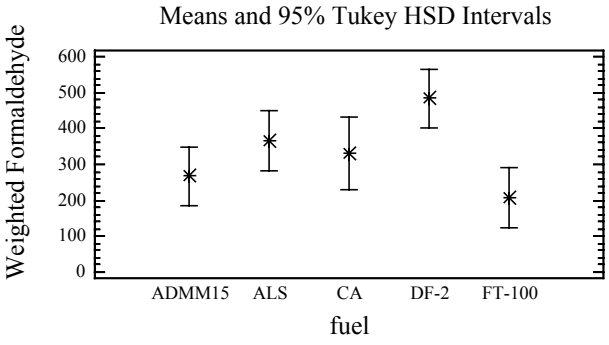


Analysis of Variance for wform - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	132754.0	4	33188.4	9.01	0.0033
RESIDUAL	33150.2	9	3683.35		
TOTAL (CORRECTED)	165904.0	13			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted formaldehyde among the fuels.



CONCLUSION: The average weighted formaldehyde for the DF-2 fuel is significantly different than the FT-100 and the ADMM15 fuels.

Multiple Range Tests for wform by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

FT-100	3	206.837	X
ADMM15	3	267.08	X
CA	2	332.429	XX
ALS	3	366.759	XX
DF-2	3	484.198	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-99.6792	166.493
ADMM15 - CA	-65.3484	186.144
ADMM15 - DF-2	*-217.118	166.493
ADMM15 - FT-100	60.2428	166.493
ALS - CA	34.3309	186.144
ALS - DF-2	-117.439	166.493
ALS - FT-100	159.922	166.493
CA - DF-2	-151.77	186.144
CA - FT-100	125.591	186.144
DF-2 - FT-100	*277.361	166.493

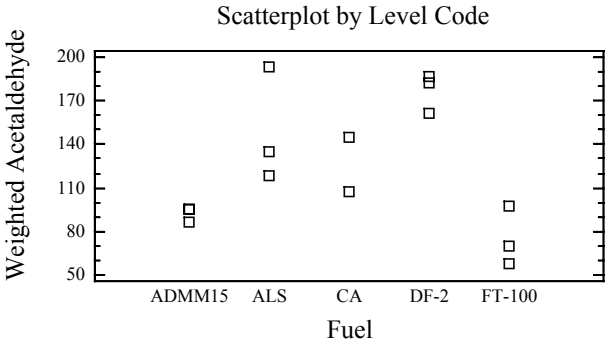
* denotes a statistically significant difference.

Multifactor ANOVA - Acetaldehyde (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wacet
Factors:
fuel

Number of complete cases: 14

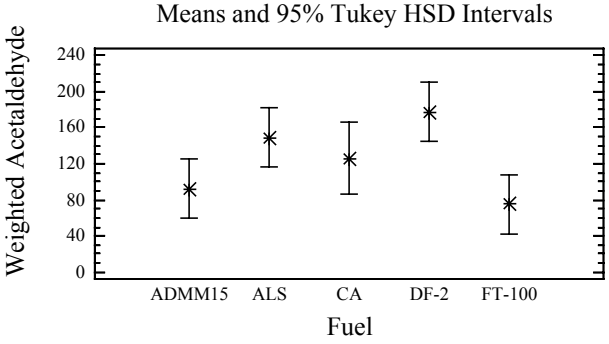


Analysis of Variance for wacet - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	20482.6	4	5120.64	9.15	0.0031
RESIDUAL	5037.78	9	559.754		
TOTAL (CORRECTED)	25520.3	13			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted acetaldehyde among the fuels.



CONCLUSION: The average weighted acetaldehyde for the DF-2 fuel is significantly different than the FT-100 or ADMM15 fuels. The FT-100 and ADMM15 fuels are not significantly different from one another. Also, the average weighted acetaldehyde for the FT-100 fuel is significantly different than the ALS fuel.

Multiple Range Tests for wacet by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	75.0123	X
ADMM15	3	92.391	XX
CA	2	126.023	XXX
ALS	3	148.784	XX
DF-2	3	177.029	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-56.3933	64.904
ADMM15 - CA	-33.6324	72.5649
ADMM15 - DF-2	*-84.6377	64.904
ADMM15 - FT-100	17.3787	64.904
ALS - CA	22.7609	72.5649
ALS - DF-2	-28.2445	64.904
ALS - FT-100	*73.772	64.904
CA - DF-2	-51.0053	72.5649
CA - FT-100	51.0111	72.5649
DF-2 - FT-100	*102.016	64.904

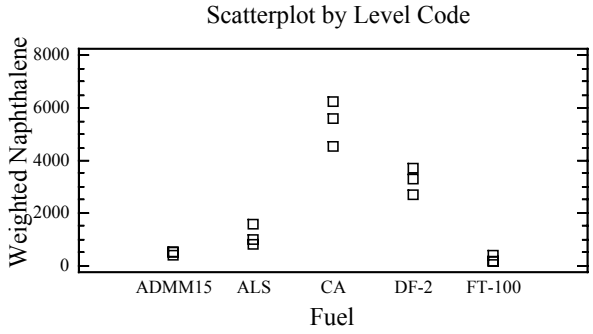
* denotes a statistically significant difference.

Multifactor ANOVA - Naphthalene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wgnap
Factors:
fuel

Number of complete cases: 15

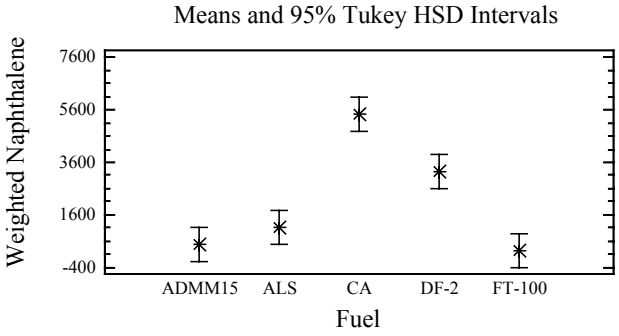


Analysis of Variance for wgnap - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	5.82625E7	4	1.45656E7	63.89	0.0000
RESIDUAL	2.27967E6	10	227967.0		
TOTAL (CORRECTED)	6.05421E7	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted naphthalene among the fuels.



CONCLUSION: There are three distinct fuel groupings with respect to the average weighted naphthalene. FT-100, ADMM15, and ALS fuels are not significantly different from one another, but they are significantly different from the other two fuels. The DF-2 and CA fuels are significantly different from one another and the remaining three fuels.

Multiple Range Tests for wgnap by fuel

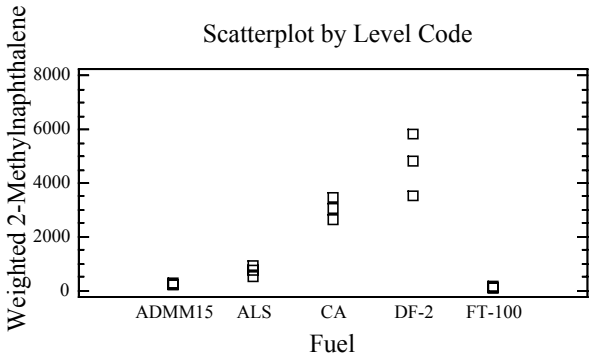
```
---------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
fuel           Count     LS Mean           Homogeneous Groups
---------------------------------------------------------------------------
FT-100         3         252.517           X
ADMM15         3         467.144           X
ALS            3         1126.8            X
DF-2           3         3226.07            X
CA             3         5435.61              X
---------------------------------------------------------------------------
Contrast                                 Difference           +/-  Limits
---------------------------------------------------------------------------
ADMM15 - ALS                              -659.659            1283.12
ADMM15 - CA                              *-4968.46            1283.12
ADMM15 - DF-2                            *-2758.93            1283.12
ADMM15 - FT-100                           214.627             1283.12
ALS - CA                                 *-4308.8             1283.12
ALS - DF-2                               *-2099.27            1283.12
ALS - FT-100                              874.286             1283.12
CA - DF-2                                *2209.53             1283.12
CA - FT-100                              *5183.09             1283.12
DF-2 - FT-100                            *2973.56             1283.12
---------------------------------------------------------------------------
* denotes a statistically significant difference.
```

Multifactor ANOVA - 2-Methylnaphthalene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wmeth2
Factors:
fuel

Number of complete cases: 15

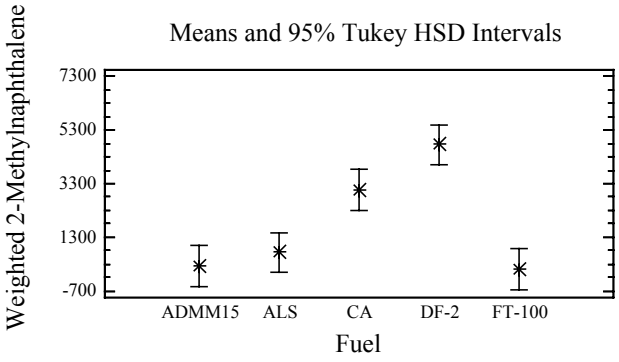


Analysis of Variance for wmeth2 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	5.0131E7	4	1.25327E7	40.17	0.0000
RESIDUAL	3.12018E6	10	312018.0		
TOTAL (CORRECTED)	5.32512E7	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted 2-Methylnaphthalene among the fuels.



CONCLUSION: There are three distinct fuel groupings with respect to the average weighted 2-Methylnaphthalene. FT-100, ADMM15, and ALS fuels are not significantly different from one another, but they are significantly different from the other two fuels. The DF-2 and CA fuels are significantly different from one another and the remaining three fuels.

Multiple Range Tests for wmeth2 by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	113.904	X
ADMM15	3	238.762	X
ALS	3	737.313	X
CA	3	3064.71	X
DF-2	3	4750.08	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-498.551	1501.14
ADMM15 - CA	*-2825.95	1501.14
ADMM15 - DF-2	*-4511.32	1501.14
ADMM15 - FT-100	124.858	1501.14
ALS - CA	*-2327.4	1501.14
ALS - DF-2	*-4012.77	1501.14
ALS - FT-100	623.409	1501.14
CA - DF-2	*-1685.37	1501.14
CA - FT-100	*2950.8	1501.14
DF-2 - FT-100	*4636.18	1501.14

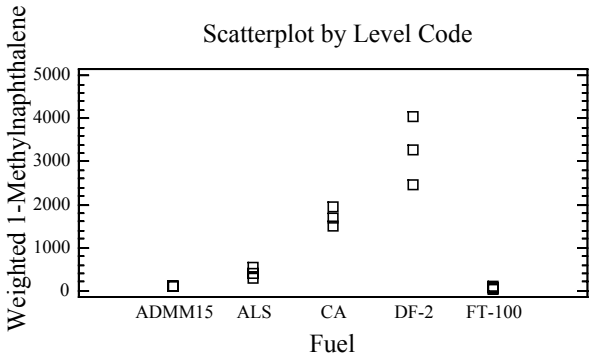
* denotes a statistically significant difference.

Multifactor ANOVA - 1-Methylnaphthalene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wmeth1
Factors:
fuel

Number of complete cases: 15

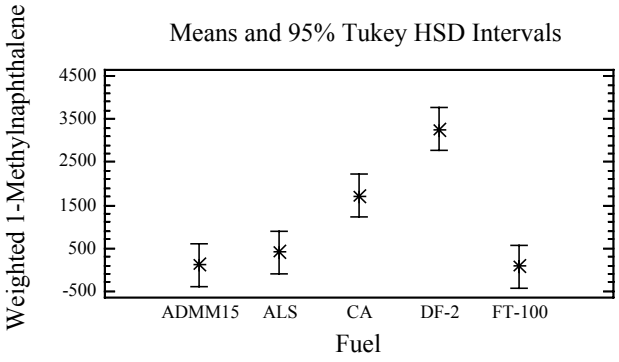


Analysis of Variance for wmeth1 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	2.27955E7	4	5.69887E6	40.86	0.0000
RESIDUAL	1.39457E6	10	139457.0		
TOTAL (CORRECTED)	2.419E7	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted 1-Methylnapthalene among the fuels.



CONCLUSION: There are three distinct fuel groupings with respect to the average weighted 1-Methylnaphthalene. FT-100, ADMM15, and ALS fuels are not significantly different from one another, but they are significantly different from the other two fuels. The DF-2 and CA fuels are significantly different from one another and the remaining three fuels.

Multiple Range Tests for wmeth1 by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	65.7216	X
ADMM15	3	111.076	X
ALS	3	409.914	X
CA	3	1712.61	X
DF-2	3	3267.99	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-298.838	1003.58
ADMM15 - CA	*-1601.54	1003.58
ADMM15 - DF-2	*-3156.91	1003.58
ADMM15 - FT-100	45.3542	1003.58
ALS - CA	*-1302.7	1003.58
ALS - DF-2	*-2858.08	1003.58
ALS - FT-100	344.192	1003.58
CA - DF-2	*-1555.38	1003.58
CA - FT-100	*1646.89	1003.58
DF-2 - FT-100	*3202.27	1003.58

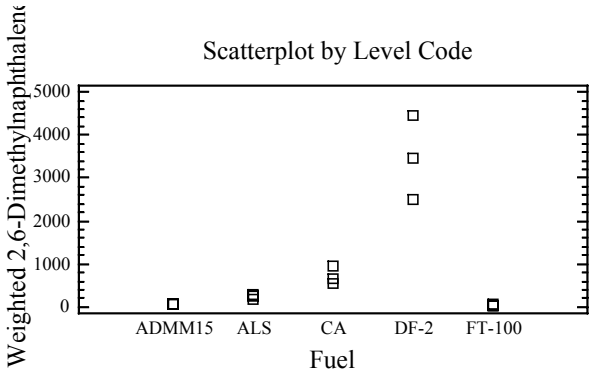
* denotes a statistically significant difference.

Multifactor ANOVA - 2,6-Dimethylnaphthalene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wdimeth
Factors:
fuel

Number of complete cases: 15

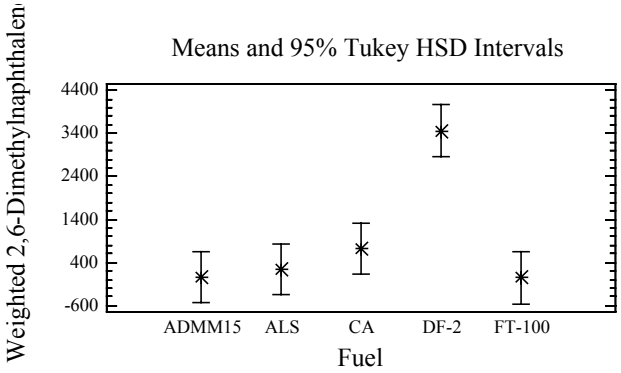


Analysis of Variance for wdimeth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	2.54445E7	4	6.36112E6	31.74	0.0000
RESIDUAL	2.00436E6	10	200436.0		
TOTAL (CORRECTED)	2.74488E7	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted 2,6-Dimethylnaphthalene among the fuels.



CONCLUSION: The average weighted 2,6-Dimethylnaphthalene for the DF-2 fuel is significantly different than the other four fuels. The average weighted 2,6-Dimethylnaphthalene among the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for wdimeth by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	44.7092	X
ADMM15	3	48.8125	X
ALS	3	242.317	X
CA	3	722.341	X
DF-2	3	3461.53	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-193.504	1203.15
ADMM15 - CA	-673.529	1203.15
ADMM15 - DF-2	*-3412.71	1203.15
ADMM15 - FT-100	4.10334	1203.15
ALS - CA	-480.025	1203.15
ALS - DF-2	*-3219.21	1203.15
ALS - FT-100	197.607	1203.15
CA - DF-2	*-2739.19	1203.15
CA - FT-100	677.632	1203.15
DF-2 - FT-100	*3416.82	1203.15

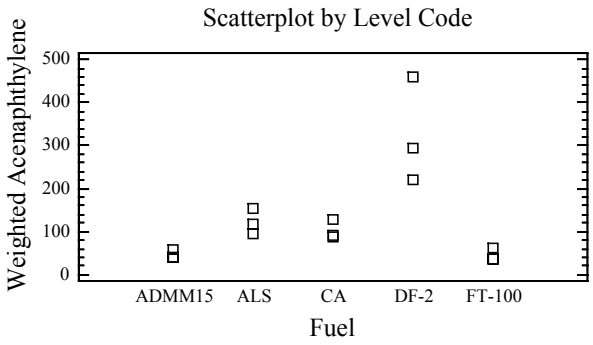
* denotes a statistically significant difference.

Multifactor ANOVA - Acenaphthylene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wgace
Factors:
fuel

Number of complete cases: 15

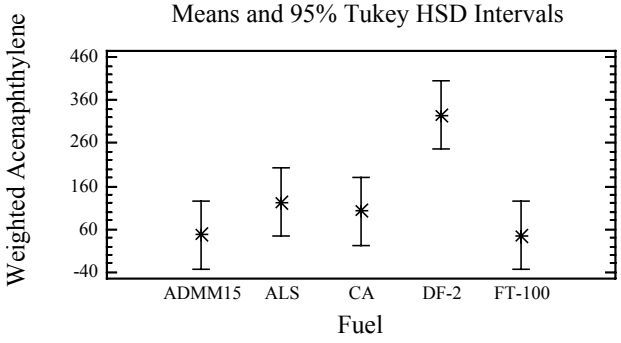


Analysis of Variance for wgace - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	158784.0	4	39696.0	11.47	0.0009
RESIDUAL	34611.0	10	3461.1		
TOTAL (CORRECTED)	193395.0	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted acenaphthylene among the fuels.



CONCLUSION: The average weighted acenaphthylene for the DF-2 fuel is significantly different than the other four fuels. The average weighted acenaphthylene among the FT-100, ADMM15, CA, and ALS fuels are not significantly different from one another.

Multiple Range Tests for wgace by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

FT-100	3	45.2115	X
ADMM15	3	46.4444	X
CA	3	102.196	X
ALS	3	122.207	X
DF-2	3	324.783	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-75.7629	158.102
ADMM15 - CA	-55.7518	158.102
ADMM15 - DF-2	*-278.339	158.102
ADMM15 - FT-100	1.23286	158.102
ALS - CA	20.011	158.102
ALS - DF-2	*-202.576	158.102
ALS - FT-100	76.9957	158.102
CA - DF-2	*-222.587	158.102
CA - FT-100	56.9847	158.102
DF-2 - FT-100	*279.571	158.102

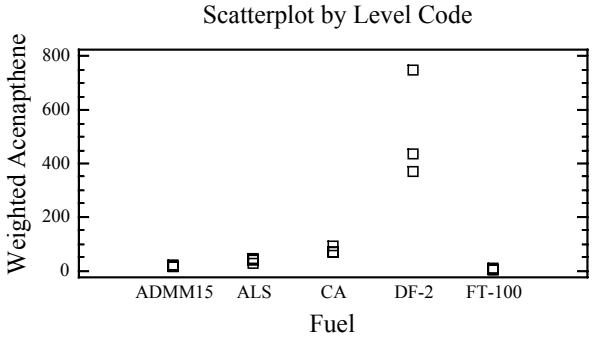
* denotes a statistically significant difference.

Multifactor ANOVA - Acenaphthene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wacen
Factors:
fuel

Number of complete cases: 15

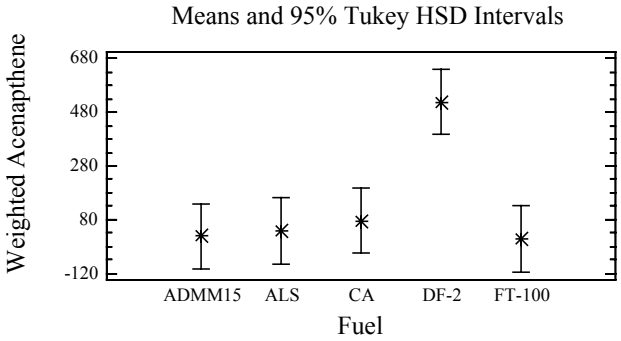


Analysis of Variance for wacen - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	566067.0	4	141517.0	17.32	0.0002
RESIDUAL	81710.1	10	8171.01		
TOTAL (CORRECTED)	647777.0	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted acenaphthene among the fuels.



CONCLUSION: The average weighted acenaphthene for the DF-2 fuel is significantly different than the other four fuels. The average weighted acenaphthene among the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for wacen by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	8.5014	X
ADMM15	3	19.1396	X
ALS	3	37.6132	X
CA	3	75.3734	X
DF-2	3	517.467	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-18.4736	242.923
ADMM15 - CA	-56.2338	242.923
ADMM15 - DF-2	*-498.327	242.923
ADMM15 - FT-100	10.6382	242.923
ALS - CA	-37.7602	242.923
ALS - DF-2	*-479.854	242.923
ALS - FT-100	29.1118	242.923
CA - DF-2	*-442.094	242.923
CA - FT-100	66.872	242.923
DF-2 - FT-100	*508.966	242.923

* denotes a statistically significant difference.

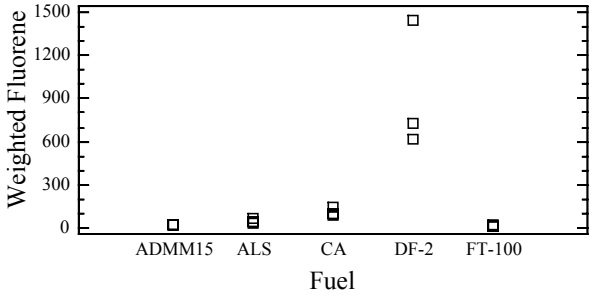
Multifactor ANOVA - Fluorene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wgflue
Factors:
fuel

Number of complete cases: 15

Scatterplot by Level Code



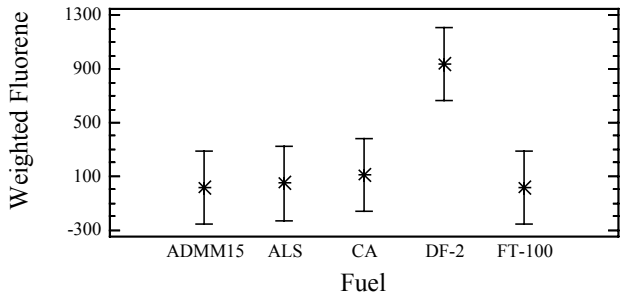
Analysis of Variance for wgflue - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1.89876E6	4	474690.0	11.55	0.0009
RESIDUAL	410827.0	10	41082.7		
TOTAL (CORRECTED)	2.30959E6	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted fluorene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average weighted fluorene for the DF-2 fuel is significantly different than the other four fuels. The average weighted fluorene among the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for wgflue by fuel

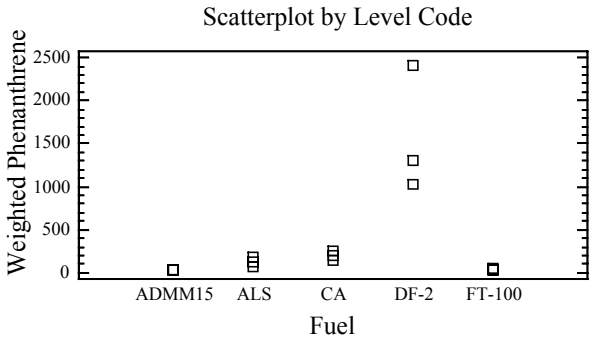
```
---------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
fuel           Count     LS Mean           Homogeneous Groups
---------------------------------------------------------------------------
ADMM15         3         15.5368           X
FT-100         3         15.9082           X
ALS            3         45.8231           X
CA             3         108.559           X
DF-2           3         931.876            X
---------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
---------------------------------------------------------------------------
ADMM15 - ALS                               -30.2864            544.704
ADMM15 - CA                                -93.022             544.704
ADMM15 - DF-2                             *-916.339            544.704
ADMM15 - FT-100                            -0.371457           544.704
ALS - CA                                   -62.7356            544.704
ALS - DF-2                                *-886.053            544.704
ALS - FT-100                               29.9149             544.704
CA - DF-2                                 *-823.317            544.704
CA - FT-100                                92.6505             544.704
DF-2 - FT-100                             *915.968             544.704
---------------------------------------------------------------------------
* denotes a statistically significant difference.
```

Multifactor ANOVA - Phenanthrene (micro g/Kw-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wgphe
Factors:
fuel

Number of complete cases: 15

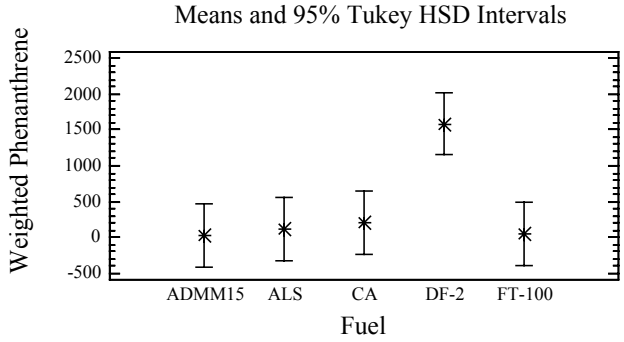


Analysis of Variance for wgphe - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	5.3621E6	4	1.34053E6	12.39	0.0007
RESIDUAL	1.082E6	10	108200.0		
TOTAL (CORRECTED)	6.4441E6	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted phenanthrene among the fuels.



CONCLUSION: The average weighted phenanthrene for the DF-2 fuel is significantly different than the other four fuels. The average weighted phenanthrene among the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for wgphe by fuel

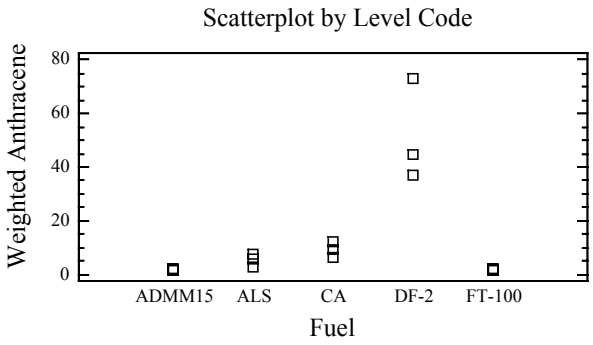
```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
fuel           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
ADMM15         3         35.5657           X
FT-100         3         40.9851           X
ALS            3         120.072           X
CA             3         199.485           X
DF-2           3         1586.24            X
-------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
-------------------------------------------------------------------------------
ADMM15 - ALS                              -84.5058             883.985
ADMM15 - CA                               -163.92              883.985
ADMM15 - DF-2                            *-1550.67             883.985
ADMM15 - FT-100                           -5.41939             883.985
ALS - CA                                  -79.4138             883.985
ALS - DF-2                               *-1466.17             883.985
ALS - FT-100                              79.0864              883.985
CA - DF-2                                *-1386.75             883.985
CA - FT-100                               158.5                883.985
DF-2 - FT-100                            *1545.25              883.985
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```

Multifactor ANOVA - Anthracene (micro g/Kw-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wgant
Factors:
fuel

Number of complete cases: 15

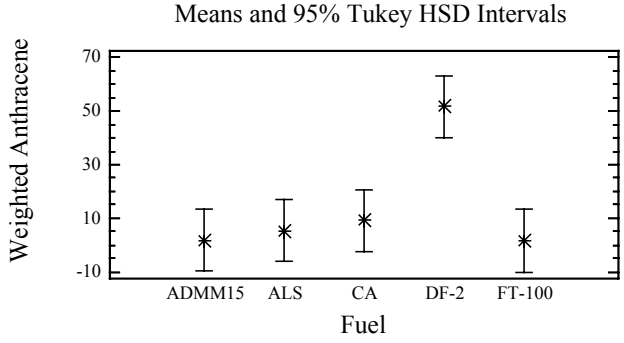


Analysis of Variance for wgant - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	5422.74	4	1355.68	18.26	0.0001
RESIDUAL	742.275	10	74.2275		
TOTAL (CORRECTED)	6165.01	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted anthracene among the fuels.



CONCLUSION: The average weighted anthracene for the DF-2 fuel is significantly different than the other four fuels. The average weighted anthracene among the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for wgant by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	1.67593	X
ADMM15	3	1.95378	X
ALS	3	5.36358	X
CA	3	9.23519	X
DF-2	3	51.5939	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-3.4098	23.1533
ADMM15 - CA	-7.28141	23.1533
ADMM15 - DF-2	*-49.6401	23.1533
ADMM15 - FT-100	0.277852	23.1533
ALS - CA	-3.87161	23.1533
ALS - DF-2	*-46.2303	23.1533
ALS - FT-100	3.68765	23.1533
CA - DF-2	*-42.3587	23.1533
CA - FT-100	7.55926	23.1533
DF-2 - FT-100	*49.9179	23.1533

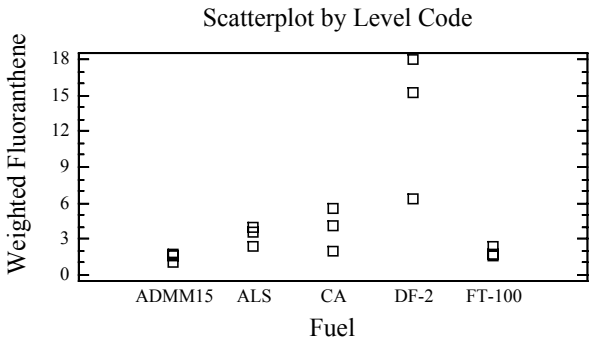
* denotes a statistically significant difference.

Multifactor ANOVA - Fluoranthene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wgflua
Factors:
fuel

Number of complete cases: 15

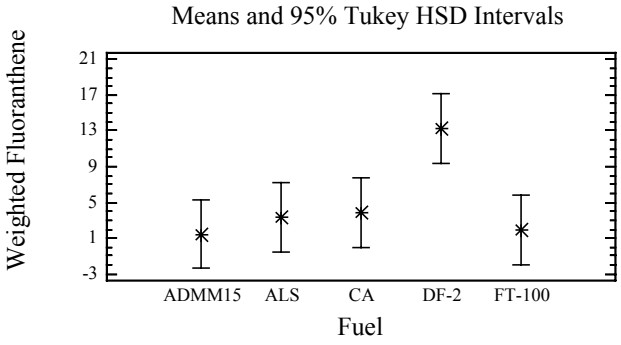


Analysis of Variance for wgflua - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	280.999	4	70.2498	8.50	0.0029
RESIDUAL	82.6177	10	8.26177		
TOTAL (CORRECTED)	363.617	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted fluoranthene among the fuels.



CONCLUSION: The average weighted fluoranthene for the DF-2 fuel is significantly different than the other four fuels. The average weighted fluoranthene among the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for wgflua by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	1.4535	X
FT-100	3	1.86965	X
ALS	3	3.29502	X
CA	3	3.92077	X
DF-2	3	13.2175	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.84153	7.72445
ADMM15 - CA	-2.46727	7.72445
ADMM15 - DF-2	*-11.764	7.72445
ADMM15 - FT-100	-0.416153	7.72445
ALS - CA	-0.625743	7.72445
ALS - DF-2	*-9.92247	7.72445
ALS - FT-100	1.42538	7.72445
CA - DF-2	*-9.29672	7.72445
CA - FT-100	2.05112	7.72445
DF-2 - FT-100	*11.3478	7.72445

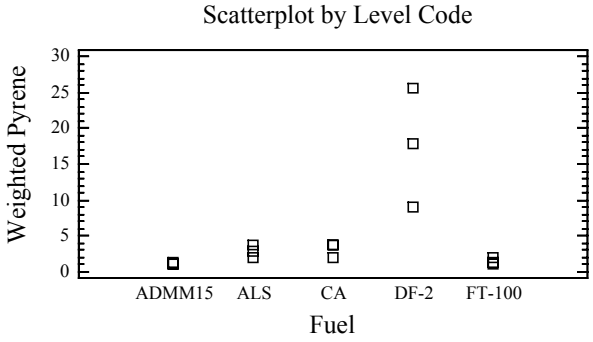
* denotes a statistically significant difference.

Multifactor ANOVA - Pyrene (micro g/kW-hr) Gaseous PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wgpyr
Factors:
fuel

Number of complete cases: 15

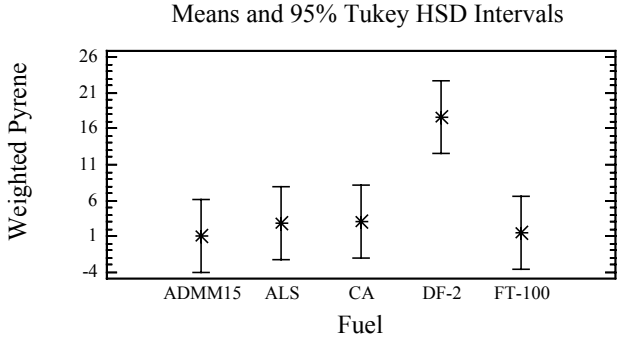


Analysis of Variance for wgpyr - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	579.075	4	144.769	10.09	0.0015
RESIDUAL	143.425	10	14.3425		
TOTAL (CORRECTED)	722.499	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted pyrene among the fuels.



CONCLUSION: The average weighted pyrene for the DF-2 fuel is significantly different than the other four fuels. The average weighted pyrene for the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for wgpyr by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

ADMM15	3	1.14171	X
FT-100	3	1.40629	X
ALS	3	2.83773	X
CA	3	3.13677	X
DF-2	3	17.5421	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.69601	10.1775
ADMM15 - CA	-1.99505	10.1775
ADMM15 - DF-2	*-16.4003	10.1775
ADMM15 - FT-100	-0.264572	10.1775
ALS - CA	-0.299041	10.1775
ALS - DF-2	*-14.7043	10.1775
ALS - FT-100	1.43144	10.1775
CA - DF-2	*-14.4053	10.1775
CA - FT-100	1.73048	10.1775
DF-2 - FT-100	*16.1358	10.1775

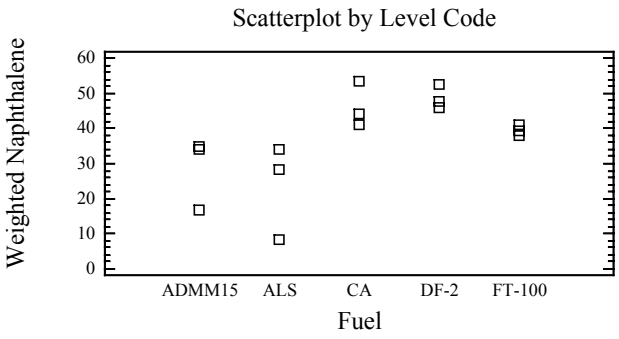
* denotes a statistically significant difference.

Multifactor ANOVA - Naphthalene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wnaphth
Factors:
fuel

Number of complete cases: 15

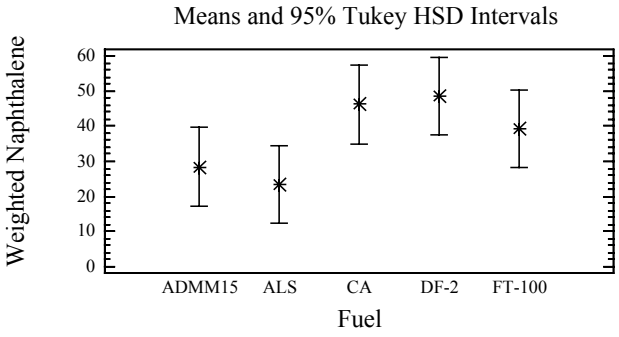


Analysis of Variance for wnaphth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1451.85	4	362.963	5.31	0.0147
RESIDUAL	682.982	10	68.2982		
TOTAL (CORRECTED)	2134.84	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average naphthalene among the fuels.



CONCLUSION: The average weighted naphthalene for the ALS fuel is significantly different from the CA and DF-2 fuels.

Multiple Range Tests for wnaphth by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ALS	3	23.446	X
ADMM15	3	28.43	XX
FT-100	3	39.378	XX
CA	3	46.1776	X
DF-2	3	48.7122	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	4.98395	22.2093
ADMM15 - CA	-17.7476	22.2093
ADMM15 - DF-2	-20.2822	22.2093
ADMM15 - FT-100	-10.948	22.2093
ALS - CA	*-22.7315	22.2093
ALS - DF-2	*-25.2661	22.2093
ALS - FT-100	-15.9319	22.2093
CA - DF-2	-2.53459	22.2093
CA - FT-100	6.79963	22.2093
DF-2 - FT-100	9.33422	22.2093

* denotes a statistically significant difference.

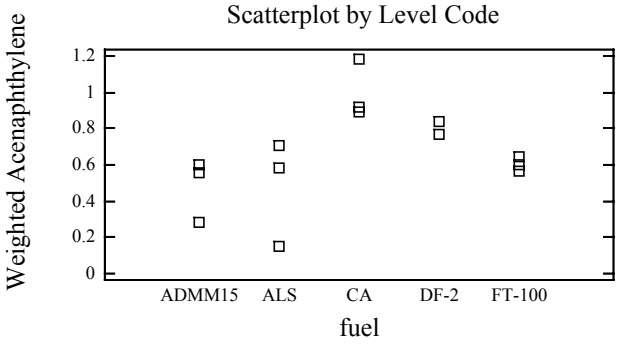
Multifactor ANOVA - Acenaphthylene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

NOTE: ALS data was imputed for repeat runs #2 and #3 because of non-detects in mode 5.

Analysis Summary

Dependent variable: wacenap
Factors:
fuel

Number of complete cases: 14

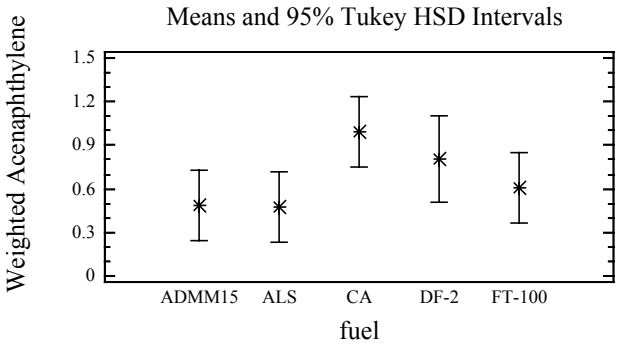


Analysis of Variance for wacenap - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.588575	4	0.147144	4.65	0.0260
RESIDUAL	0.284701	9	0.0316334		
TOTAL (CORRECTED)	0.873276	13			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted acenaphthylene among the fuels.



CONCLUSION: The average weighted acenaphthylene for the CA fuel is significantly different from the ADMM15 and ALS fuels.

Multiple Range Tests for wacenap by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ALS	3	0.47797	X
ADMM15	3	0.480728	X
FT-100	3	0.603505	XX
DF-2	2	0.807415	XX
CA	3	0.996603	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	0.00275813	0.487917
ADMM15 - CA	*-0.515875	0.487917
ADMM15 - DF-2	-0.326687	0.545508
ADMM15 - FT-100	-0.122777	0.487917
ALS - CA	*-0.518633	0.487917
ALS - DF-2	-0.329445	0.545508
ALS - FT-100	-0.125536	0.487917
CA - DF-2	0.189188	0.545508
CA - FT-100	0.393098	0.487917
DF-2 - FT-100	0.203909	0.545508

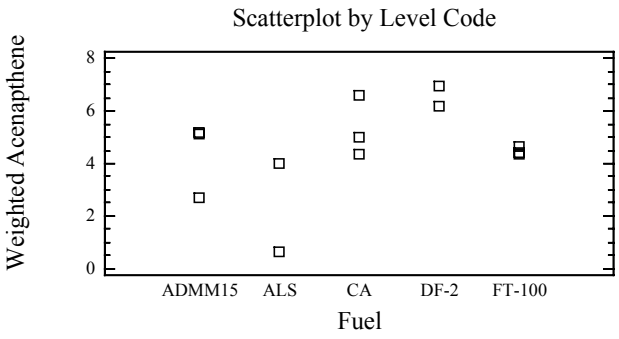
* denotes a statistically significant difference.

Multifactor ANOVA - Acenaphthene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wacenat
Factors:
fuel

Number of complete cases: 13

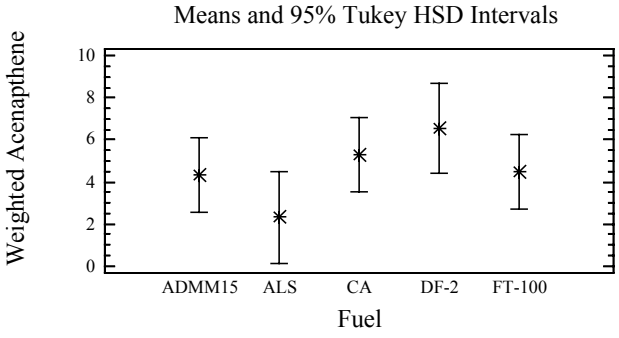


Analysis of Variance for wacenat - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	19.9901	4	4.99754	3.18	0.0767
RESIDUAL	12.5657	8	1.57072		
TOTAL (CORRECTED)	32.5559	12			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average acenaphthene among the fuels.



CONCLUSION: No statistically significant differences in the average acenaphthene among the fuels.

Multiple Range Tests for wacenat by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

ALS	2	2.31375	X
ADMM15	3	4.33291	X
FT-100	3	4.47144	X
CA	3	5.32256	X
DF-2	2	6.56407	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	2.01916	3.94549
ADMM15 - CA	-0.989647	3.52895
ADMM15 - DF-2	-2.23116	3.94549
ADMM15 - FT-100	-0.138534	3.52895
ALS - CA	-3.0088	3.94549
ALS - DF-2	-4.25032	4.32207
ALS - FT-100	-2.15769	3.94549
CA - DF-2	-1.24151	3.94549
CA - FT-100	0.851114	3.52895
DF-2 - FT-100	2.09263	3.94549

* denotes a statistically significant difference.

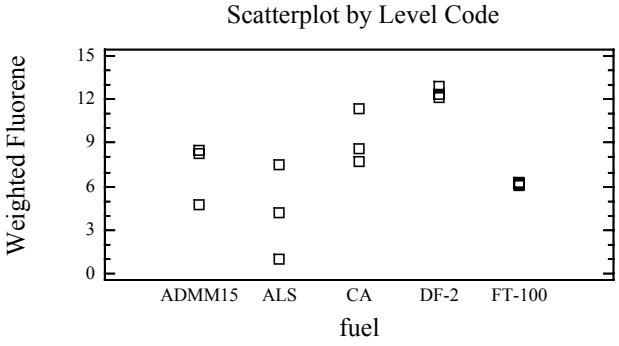
Multifactor ANOVA - Fluorene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

NOTE: ALS data was imputed for repeat runs #3 and #3 because of non-detects in modes 5 and 11.

Analysis Summary

Dependent variable: wfluore
Factors:
fuel

Number of complete cases: 15

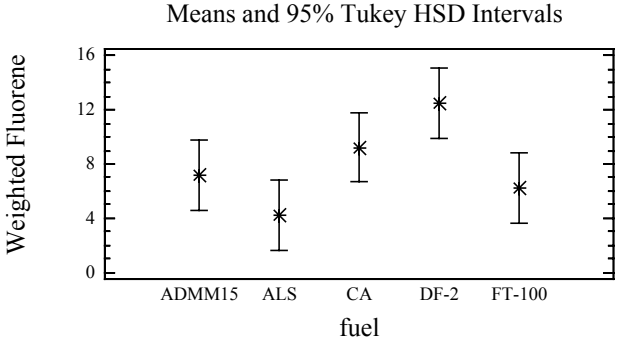


Analysis of Variance for wfluore - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	119.377	4	29.8442	8.09	0.0035
RESIDUAL	36.8724	10	3.68724		
TOTAL (CORRECTED)	156.249	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted fluorene among the fuels.



CONCLUSION: The average weighted fluorene for the DF-2 fuel is significantly different from the ADMM15, FT-100, and ALS fuels.

Multiple Range Tests for wfluore by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ALS	3	4.21444	X
FT-100	3	6.20745	X
ADMM15	3	7.17305	X
CA	3	9.22614	XX
DF-2	3	12.4896	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	2.95861	5.16038
ADMM15 - CA	-2.05309	5.16038
ADMM15 - DF-2	*-5.31652	5.16038
ADMM15 - FT-100	0.965605	5.16038
ALS - CA	-5.01171	5.16038
ALS - DF-2	*-8.27514	5.16038
ALS - FT-100	-1.99301	5.16038
CA - DF-2	-3.26343	5.16038
CA - FT-100	3.0187	5.16038
DF-2 - FT-100	*6.28213	5.16038

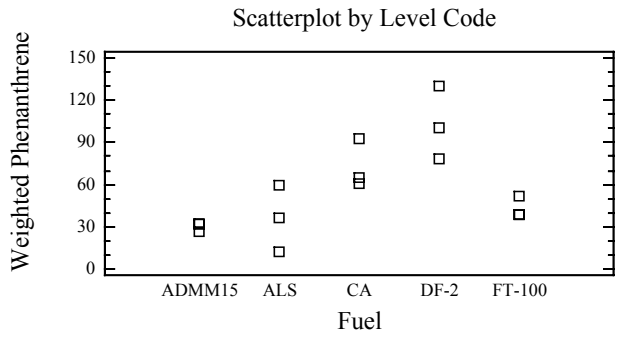
* denotes a statistically significant difference.

Multifactor ANOVA - Phenanthrene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wphenant
Factors:
fuel

Number of complete cases: 15

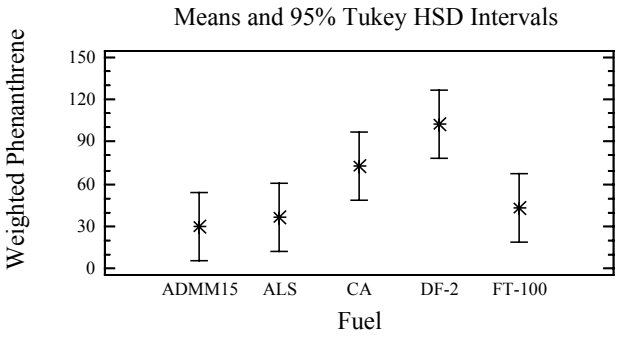


Analysis of Variance for wphenant - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	11232.8	4	2808.19	8.58	0.0028
RESIDUAL	3271.32	10	327.132		
TOTAL (CORRECTED)	14504.1	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted phenanthrene among the fuels.



CONCLUSION: The average weighted phenanthrene for the DF-2 fuel is significantly different than the ADMM15, ALS, and FT-100 fuels. The average weighted phenanthrene for the ADMM15, ALS, FT-100, and CA fuels are not significantly different from one another.

Multiple Range Tests for wphenant by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	29.8105	X
ALS	3	36.0033	X
FT-100	3	43.0115	X
CA	3	72.8461	XX
DF-2	3	103.015	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-6.19275	48.6063
ADMM15 - CA	-43.0356	48.6063
ADMM15 - DF-2	*-73.2044	48.6063
ADMM15 - FT-100	-13.201	48.6063
ALS - CA	-36.8428	48.6063
ALS - DF-2	*-67.0116	48.6063
ALS - FT-100	-7.00828	48.6063
CA - DF-2	-30.1688	48.6063
CA - FT-100	29.8346	48.6063
DF-2 - FT-100	*60.0034	48.6063

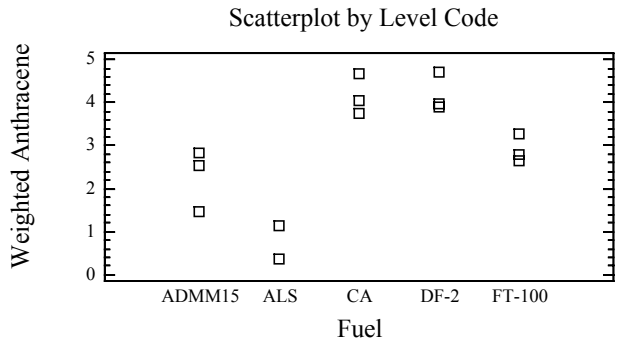
* denotes a statistically significant difference.

Multifactor ANOVA - Anthracene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wanthr
Factors:
fuel

Number of complete cases: 14

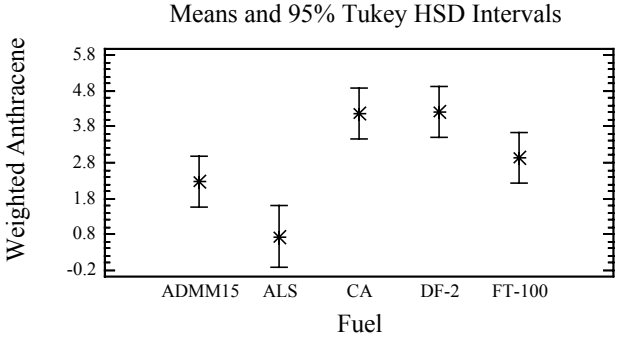


Analysis of Variance for wanthr - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	20.1205	4	5.03012	18.78	0.0002
RESIDUAL	2.41047	9	0.26783		
TOTAL (CORRECTED)	22.531	13			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted anthracene among the fuels.



CONCLUSION: The average weighted anthracene for the ALS fuel is significantly different from the CA, DF-2, and FT-100 fuels. Also, the ADMM15 fuel has a significantly different weighted anthracene than the CA and DF-2 fuels.

Multiple Range Tests for wanthr by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

ALS	2	0.737556	X
ADMM15	3	2.28698	XX
FT-100	3	2.91967	XX
CA	3	4.16059	X
DF-2	3	4.19718	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	1.54942	1.5873
ADMM15 - CA	*-1.87361	1.41972
ADMM15 - DF-2	*-1.91021	1.41972
ADMM15 - FT-100	-0.632691	1.41972
ALS - CA	*-3.42303	1.5873
ALS - DF-2	*-3.45963	1.5873
ALS - FT-100	*-2.18211	1.5873
CA - DF-2	-0.0365957	1.41972
CA - FT-100	1.24092	1.41972
DF-2 - FT-100	1.27752	1.41972

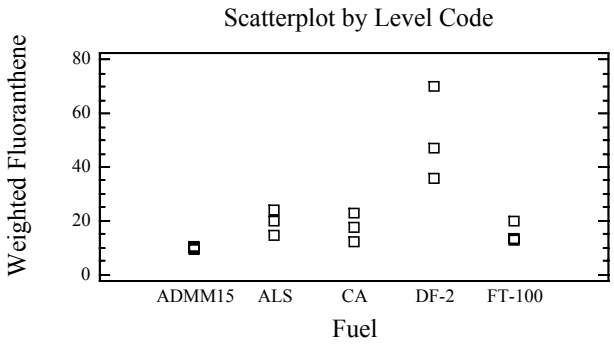
* denotes a statistically significant difference.

Multifactor ANOVA - Fluoranthene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Mode 5, 6, 10, and 11

Analysis Summary

Dependent variable: wfluora
Factors:
fuel

Number of complete cases: 15

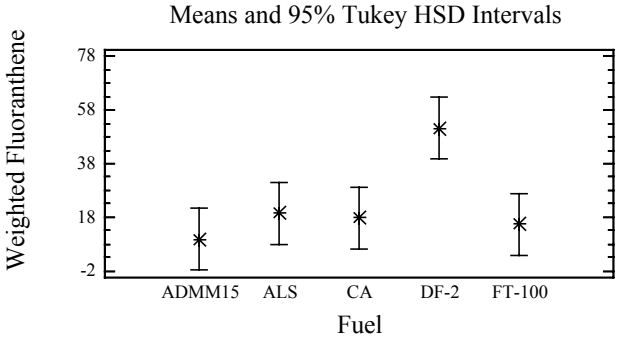


Analysis of Variance for wfluora - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	3191.45	4	797.862	10.78	0.0012
RESIDUAL	739.933	10	73.9933		
TOTAL (CORRECTED)	3931.38	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted fluoranthene among the fuels.



CONCLUSION: The average weighted fluoranthene for the DF-2 fuel is significantly different from the remaining four fuels. The ADMM15, FT-100, CA, and ALS fuels are not significantly different from one another with respect to the average weighted fluoranthene.

Multiple Range Tests for wfluora by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	9.82889	X
FT-100	3	15.4822	X
CA	3	17.7845	X
ALS	3	19.5387	X
DF-2	3	51.1942	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-9.70982	23.1168
ADMM15 - CA	-7.95564	23.1168
ADMM15 - DF-2	*-41.3653	23.1168
ADMM15 - FT-100	-5.65329	23.1168
ALS - CA	1.75417	23.1168
ALS - DF-2	*-31.6555	23.1168
ALS - FT-100	4.05653	23.1168
CA - DF-2	*-33.4097	23.1168
CA - FT-100	2.30236	23.1168
DF-2 - FT-100	*35.712	23.1168

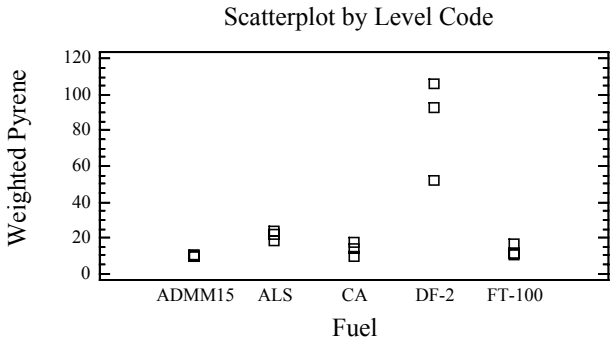
* denotes a statistically significant difference.

Multifactor ANOVA - Pyrene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wpyrene
Factors:
fuel

Number of complete cases: 15

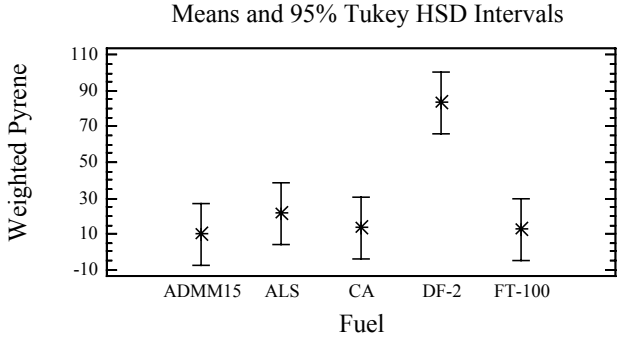


Analysis of Variance for wpyrene - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	11677.2	4	2919.3	17.72	0.0002
RESIDUAL	1647.19	10	164.719		
TOTAL (CORRECTED)	13324.4	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted pyrene among the fuels.



CONCLUSION: The average weighted pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The ADMM15, FT-100, CA, and ALS fuels are not significantly different from one another with respect to the weighted pyrene.

Multiple Range Tests for wpyrene by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

ADMM15	3	9.98398	X
FT-100	3	12.7075	X
CA	3	13.6715	X
ALS	3	21.2961	X
DF-2	3	83.5337	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-11.3121	34.4908
ADMM15 - CA	-3.68749	34.4908
ADMM15 - DF-2	*-73.5497	34.4908
ADMM15 - FT-100	-2.7235	34.4908
ALS - CA	7.62463	34.4908
ALS - DF-2	*-62.2376	34.4908
ALS - FT-100	8.58862	34.4908
CA - DF-2	*-69.8622	34.4908
CA - FT-100	0.963989	34.4908
DF-2 - FT-100	*70.8262	34.4908

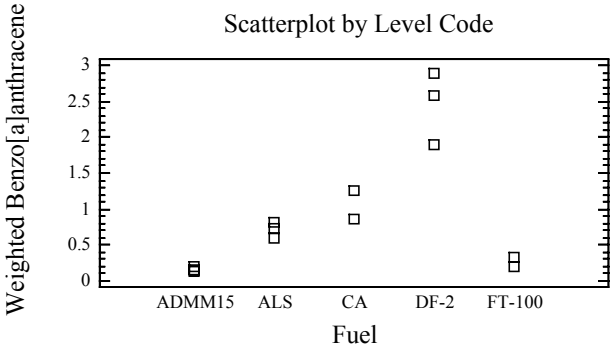
* denotes a statistically significant difference.

Multifactor ANOVA - Benzo[a]anthracene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbenzoaa
Factors:
fuel

Number of complete cases: 13

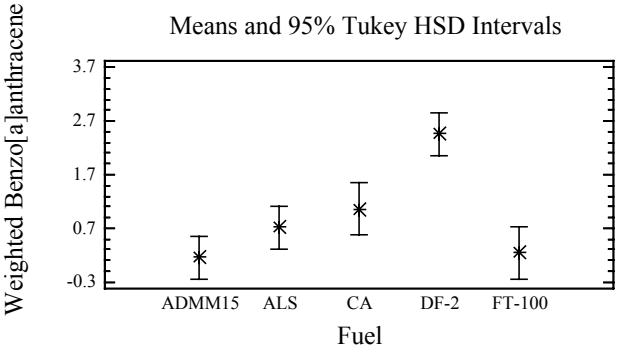


Analysis of Variance for wbenzoaa - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	9.85566	4	2.46391	30.83	0.0001
RESIDUAL	0.639289	8	0.0799112		
TOTAL (CORRECTED)	10.4949	12			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted benzo[a]anthracene among the fuels.



CONCLUSION: The average weighted benzo[a]anthracene for the DF-2 fuel is significantly different than the remaining four fuels. Also, the average weighted benzo[a]anthracene for the CA fuel is significantly different than the ADMM15 fuel.

Multiple Range Tests for wbenzoaa by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	0.154966	X
FT-100	2	0.253052	XX
ALS	3	0.712476	XX
CA	2	1.06269	X
DF-2	3	2.45533	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.55751	0.795977
ADMM15 - CA	*-0.907724	0.88993
ADMM15 - DF-2	*-2.30037	0.795977
ADMM15 - FT-100	-0.0980866	0.88993
ALS - CA	-0.350214	0.88993
ALS - DF-2	*-1.74286	0.795977
ALS - FT-100	0.459424	0.88993
CA - DF-2	*-1.39264	0.88993
CA - FT-100	0.809638	0.974869
DF-2 - FT-100	*2.20228	0.88993

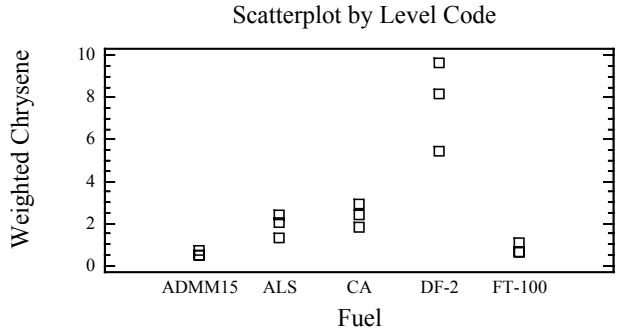
* denotes a statistically significant difference.

Multifactor ANOVA - Chrysene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wchrysen
Factors:
fuel

Number of complete cases: 15

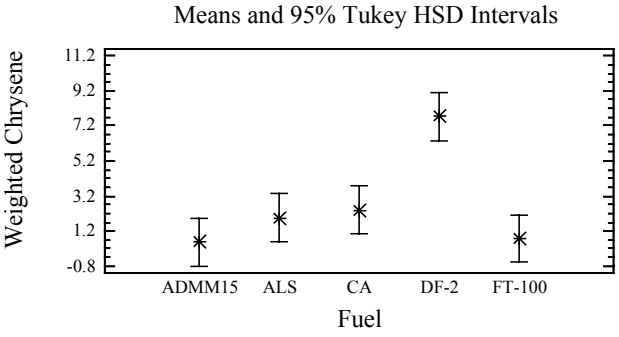


Analysis of Variance for wchrysen - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	102.637	4	25.6593	24.85	0.0000
RESIDUAL	10.3272	10	1.03272		
TOTAL (CORRECTED)	112.964	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted chyrsene among the fuels.



CONCLUSION: The average weighted chrysene for the DF-2 fuel is significantly different than the remaining four fuels. The ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another with respect to the average weighted chrysene.

Multiple Range Tests for wchrysen by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

ADMM15	3	0.585974	X
FT-100	3	0.773542	X
ALS	3	1.93602	X
CA	3	2.39139	X
DF-2	3	7.73531	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.35005	2.73101
ADMM15 - CA	-1.80542	2.73101
ADMM15 - DF-2	*-7.14934	2.73101
ADMM15 - FT-100	-0.187568	2.73101
ALS - CA	-0.455369	2.73101
ALS - DF-2	*-5.79929	2.73101
ALS - FT-100	1.16248	2.73101
CA - DF-2	*-5.34392	2.73101
CA - FT-100	1.61785	2.73101
DF-2 - FT-100	*6.96177	2.73101

* denotes a statistically significant difference.

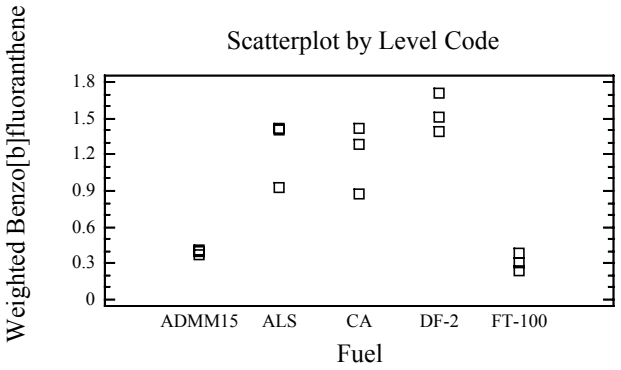
Multifactor ANOVA - Benzo[b]fluoranthene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

NOTE: CA data was imputed for repeat runs #1 and #2 because of non-detects in modes 5 and 11.

Analysis Summary

Dependent variable: wbenzobf
Factors:
fuel

Number of complete cases: 15

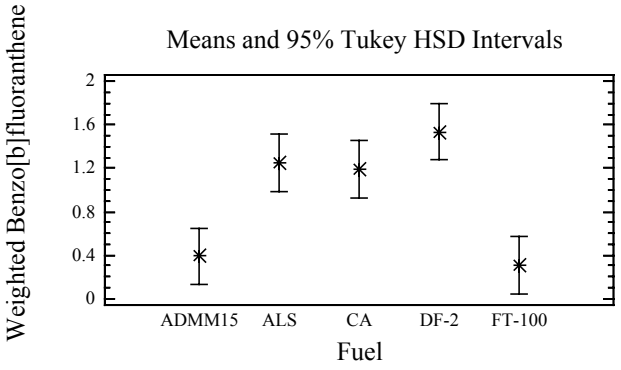


Analysis of Variance for wbenzobf - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	3.67553	4	0.918882	23.96	0.0000
RESIDUAL	0.383537	10	0.0383537		
TOTAL (CORRECTED)	4.05907	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted benzo[b]fluoranthene among the fuels.



CONCLUSION: There are two distinct fuel groupings with respect to the average weighted benzo[b]fluoranthene. The ADMM15 and FT-100 fuels are not significantly different from one another, but are different from the remaining three fuels. The ALS, CA, and DF-2 fuels are not significantly different from one another.

Multiple Range Tests for wbenzobf by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	0.3046	X
ADMM15	3	0.389343	X
CA	3	1.18968	X
ALS	3	1.25332	X
DF-2	3	1.53819	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.863973	0.526302
ADMM15 - CA	*-0.800341	0.526302
ADMM15 - DF-2	*-1.14885	0.526302
ADMM15 - FT-100	0.0847435	0.526302
ALS - CA	0.063632	0.526302
ALS - DF-2	-0.284877	0.526302
ALS - FT-100	*0.948716	0.526302
CA - DF-2	-0.348509	0.526302
CA - FT-100	*0.885084	0.526302
DF-2 - FT-100	*1.23359	0.526302

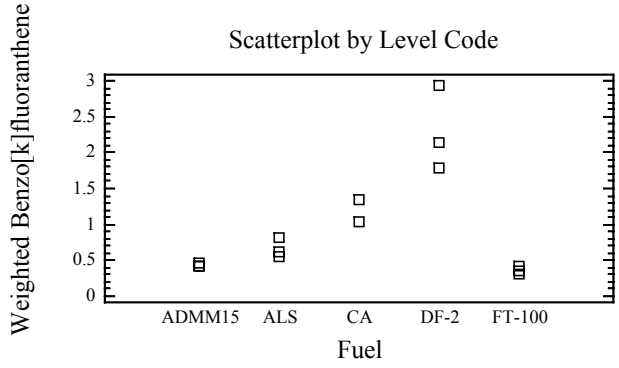
* denotes a statistically significant difference.

Multifactor ANOVA - Benzo[k]fluoranthene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbenzokf
Factors:
fuel

Number of complete cases: 14

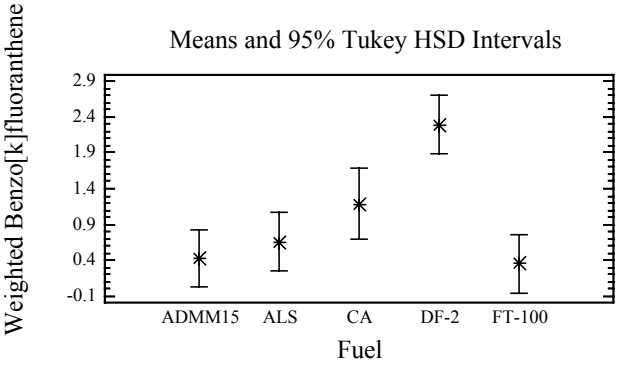


Analysis of Variance for wbenzokf - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	7.67509	4	1.91877	22.00	0.0001
RESIDUAL	0.784911	9	0.0872123		
TOTAL (CORRECTED)	8.46	13			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[k]fluoranthene among the fuels.



CONCLUSION: The average weighted benzo[k]fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another with respect to the average weighted benzo[k]fluoranthene.

Multiple Range Tests for wbenzokf by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	0.353869	X
ADMM15	3	0.423556	X
ALS	3	0.657605	X
CA	2	1.18863	X
DF-2	3	2.29314	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.234049	0.810144
ADMM15 - CA	-0.765074	0.905768
ADMM15 - DF-2	*-1.86958	0.810144
ADMM15 - FT-100	0.0696864	0.810144
ALS - CA	-0.531025	0.905768
ALS - DF-2	*-1.63553	0.810144
ALS - FT-100	0.303735	0.810144
CA - DF-2	*-1.10451	0.905768
CA - FT-100	0.83476	0.905768
DF-2 - FT-100	*1.93927	0.810144

* denotes a statistically significant difference.

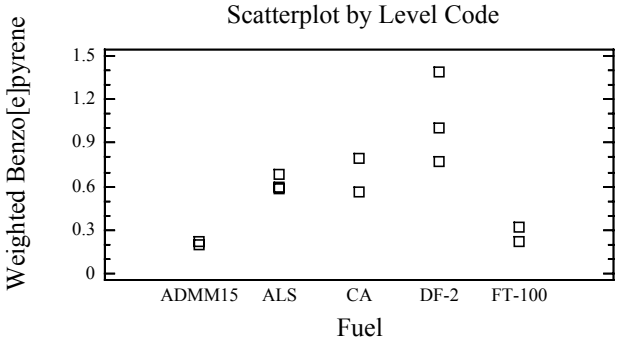
Multifactor ANOVA - Benzo[e]pyrene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

NOTE: DF-2 data was imputed for repeat runs #2 and #3 because of non-detects in modes 5 and 6.

Analysis Summary

Dependent variable: wbenzoep
Factors:
fuel

Number of complete cases: 12

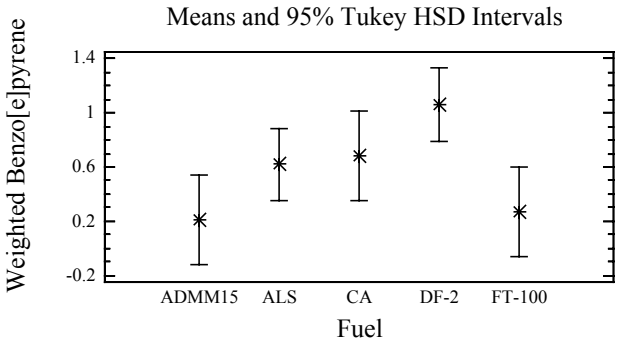


Analysis of Variance for wbenzoep - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1.17031	4	0.292577	8.63	0.0077
RESIDUAL	0.237445	7	0.0339207		
TOTAL (CORRECTED)	1.40775	11			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average weighted benzo[e]pyrene among the fuels.



CONCLUSION: The average weighted benzo[e]pyrene for the DF-2 fuel is significantly different than the ADMM15 and FT-100 fuels.

Multiple Range Tests for wbenzoep by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	2	0.210091	X
FT-100	2	0.267075	X
ALS	3	0.620611	XX
CA	2	0.679916	XX
DF-2	3	1.05916	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.41052	0.599891
ADMM15 - CA	-0.469825	0.657148
ADMM15 - DF-2	*-0.84907	0.599891
ADMM15 - FT-100	-0.0569841	0.657148
ALS - CA	-0.0593047	0.599891
ALS - DF-2	-0.43855	0.536559
ALS - FT-100	0.353536	0.599891
CA - DF-2	-0.379245	0.599891
CA - FT-100	0.412841	0.657148
DF-2 - FT-100	*0.792086	0.599891

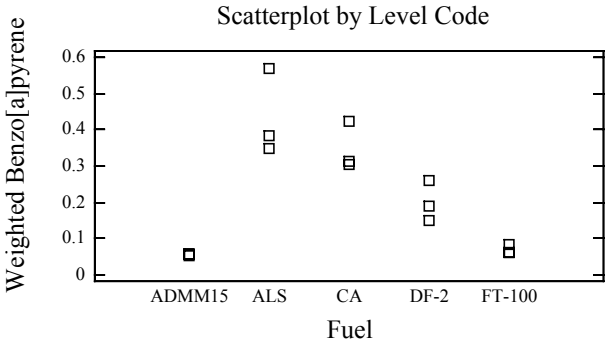
* denotes a statistically significant difference.

Multifactor ANOVA - Benzo[a]pyrene (micro g/kW-hr) Soluble PAH
LPP Only Weighted Modes 5, 6, 10, and 11

Analysis Summary

Dependent variable: wbenzoapy
Factors:
fuel

Number of complete cases: 15

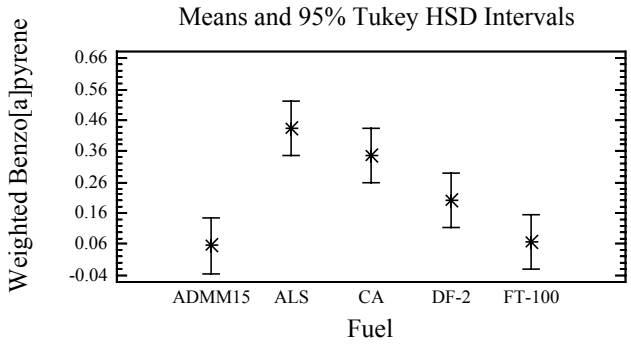


Analysis of Variance for wbenzoapy - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.338272	4	0.084568	19.40	0.0001
RESIDUAL	0.0435972	10	0.00435972		
TOTAL (CORRECTED)	0.381869	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[a]pyrene among the fuels.



CONCLUSION: The average weighted benzo[a]pyrene for the ADMM15 and FT-100 fuels is significantly different than the CA and ALS fuels. Also, ALS fuel has a significantly different weighted benzo[a]pyrene than the DF-2 fuel.

Multiple Range Tests for wbenzoapy by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	0.05479	X
FT-100	3	0.06841	X
DF-2	3	0.200233	XX
CA	3	0.346693	XX
ALS	3	0.434583	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.379793	0.177444
ADMM15 - CA	*-0.291903	0.177444
ADMM15 - DF-2	-0.145443	0.177444
ADMM15 - FT-100	-0.01362	0.177444
ALS - CA	0.08789	0.177444
ALS - DF-2	*0.23435	0.177444
ALS - FT-100	*0.366173	0.177444
CA - DF-2	0.14646	0.177444
CA - FT-100	*0.278283	0.177444
DF-2 - FT-100	0.131823	0.177444

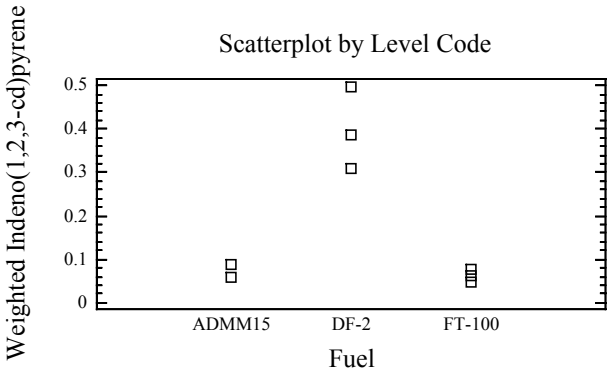
* denotes a statistically significant difference.

Multifactor ANOVA - Indeno(1,2,3-cd)pyrene (micro g/kW-hr) Soluble PAH
LPP Only for Three Fuels Weighted Modes 5,6,10, and 11

Analysis Summary

Dependent variable: windeno
Factors:
fuel

Number of complete cases: 8

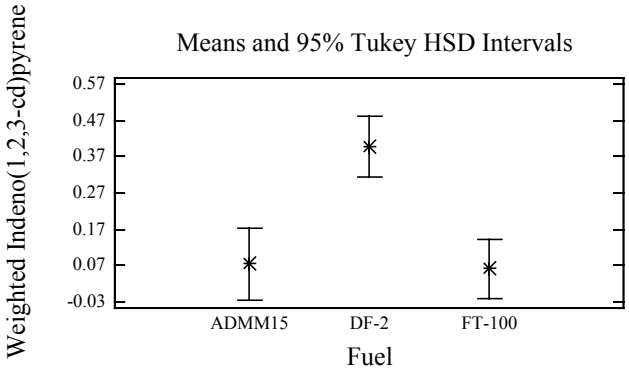


Analysis of Variance for windeno - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.206571	2	0.103285	26.79	0.0021
RESIDUAL	0.0192752	5	0.00385505		
TOTAL (CORRECTED)	0.225846	7			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average indeno(1,2,3-cd)pyrene among the fuels.



CONCLUSION: The average indeno(1,2,3-cd)pyrene for the ADMM15 and FT-100 fuels are not significantly different from one another, but both at significantly different from the DF-2 fuel.

Multiple Range Tests for windeno by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	0.0612667	X
ADMM15	2	0.073095	X
DF-2	3	0.397783	X

Contrast	Difference	+/- Limits
ADMM15 - DF-2	*-0.324688	0.184423
ADMM15 - FT-100	0.0118283	0.184423
DF-2 - FT-100	*0.336517	0.164953

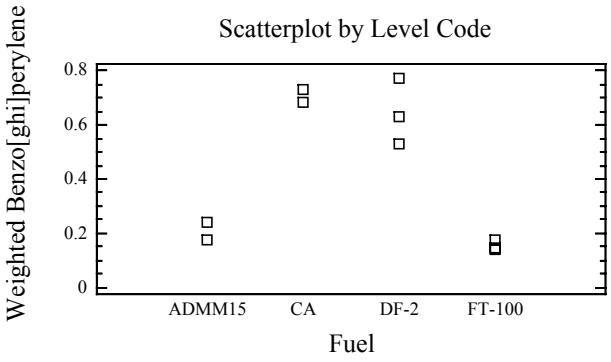
* denotes a statistically significant difference.

Multifactor ANOVA - Benzo[ghi]perylene (micro g/kW-hr) Soluble PAH
LPP Only for Four Fuels Weighted Modes 5,6,10, and 11

Analysis Summary

Dependent variable: wbenzogpe
Factors:
fuel

Number of complete cases: 10

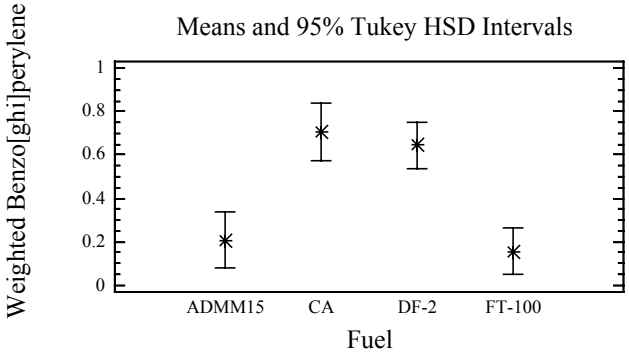


Analysis of Variance for wbenzogpe - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.615787	3	0.205262	35.64	0.0003
RESIDUAL	0.0345556	6	0.00575926		
TOTAL (CORRECTED)	0.650342	9			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[ghi]perylene among the fuels.



CONCLUSION: The average benzo[ghi]perylene for the FT-100 and ADMM15 fuels are significantly different from the DF-2 and CA fuels, but not significantly different from one another. Also, the DF-2 and CA fuels are not significantly different from one another.

Multiple Range Tests for wbenzogpe by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	0.154067	X
ADMM15	2	0.208495	X
DF-2	3	0.64388	X
CA	2	0.70622	X

Contrast	Difference	+/- Limits
ADMM15 - CA	*-0.497725	0.261841
ADMM15 - DF-2	*-0.435385	0.239027
ADMM15 - FT-100	0.0544283	0.239027
CA - DF-2	0.06234	0.239027
CA - FT-100	*0.552153	0.239027
DF-2 - FT-100	*0.489813	0.213793

* denotes a statistically significant difference.

APPENDIX E

ANOVA for Modal LPP

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Total Particulates E-3
BSNOX E-6
BSHC E-9
BSCO E-12
BSCO2 ..... E-15
BSSOF E-18
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1,3 Butadiene Toxic Gaseous Emissions E-24
Formaldehyde Toxic Gaseous Emissions E-27
Acetaldehyde Toxic Gaseous Emissions E-30
Naphthalene Gaseous PAH E-33
2-Methylnaphthalene Gaseous PAH E-36
1-Methylnaphthalene Gaseous PAH E-39
2,6-Dimethylnaphthalene (µg/kW-hr) Gaseous PAH E-42
Acenaphthylene (µg/kW-hr) Gaseous PAH E-45
Acenaphthene (µg/kW-hr) Gaseous PAH E-48
Fluorene (µg/kW-hr) Gaseous PAH E-51
Phenanthrene (µg/kW-hr) Gaseous PAH E-54
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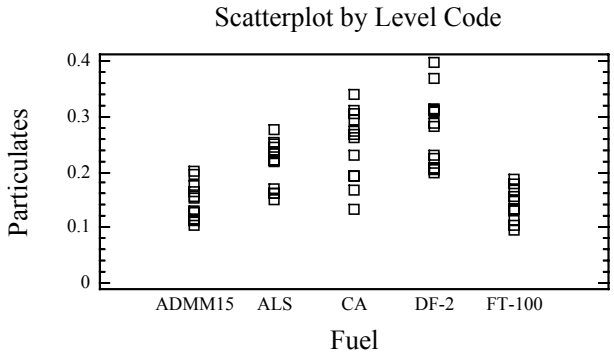
Fluoranthene (µg/kW-hr) Gaseous PAH E-60
Pyrene (µg/kW-hr) Gaseous PAH E-63
Naphthalene (µg/kW-hr) Soluble PAH E-66
Acenaphthylene (µg/kW-hr) Soluble PAH E-69
Acenaphthene (µg/kW-hr) Soluble PAH E-72
Fluorene (µg/kW-hr) Soluble PAH E-75
Phenanthrene (µg/kW-hr) Soluble PAH E-78
Anthracene (µg/kW-hr) Soluble PAH E-81
Fluoranthene (µg/kW-hr) Soluble PAH E-84
Pyrene (µg/kW-hr) Soluble PAH E-87
Benzo[a]anthracene (µg/kW-hr) Soluble PAH E-90
Chrysene (µg/kW-hr) Soluble PAH E-93
Benzo[b]fluoranthene (µg/kW-hr) Soluble PAH E-96
Benzo[k]fluoranthene (µg/kW-hr) Soluble PAH E-99
Benzo[e]pyrene (µg/kW-hr) Soluble PAH E-102
Benzo[a]pyrene (µg/kW-hr) Soluble PAH E-105
Indeno(1,2,3-cd)pyrene (µg/kW-hr) Soluble PAH E-108
Dibenzo[a,h]anthracene (µg/kW-hr) Soluble PAH E-111
Benzo[ghi]perylene (µg/kW-hr) Soluble PAH E-114

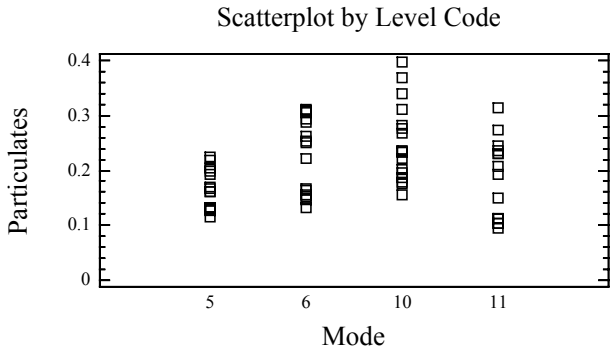
Multifactor ANOVA - Total Particulates (g/kW-hr)
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: PARTIC
Factors:
FUEL
MODE
Selection variable: MODE < 12

Number of complete cases: 62



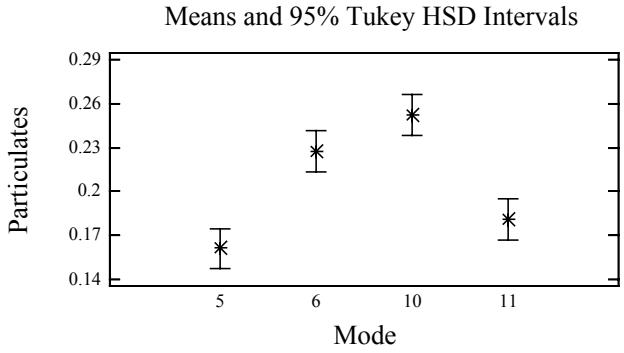


Analysis of Variance for PARTIC - Type III Sums of Squares

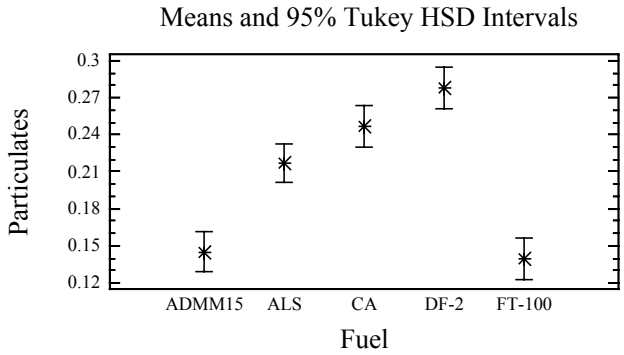
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	0.180096	4	0.0450239	55.43	0.0000
B:MODE	0.0812661	3	0.0270887	33.35	0.0000
INTERACTIONS					
AB	0.0203674	12	0.00169728	2.09	0.0392
RESIDUAL	0.0341148	42	0.000812257		
TOTAL (CORRECTED)	0.31392	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average particulates among the fuels, modes, and fuel*mode interaction.



CONCLUSION: Average particulate at Modes 5 and 11 are not significantly different from one another. Average particulate at Modes 6 and 10 are not significantly different from one another. Average particulate at modes 5 and 11 are significantly different than modes 6 and 10.



CONCLUSION: Average particulate at fuels FT-100 and ADMM15 are not significantly different
from one another, but are different than the other 3 fuels. The average particulate at Fuel ALS is significantly different than Fuel DF-2. The CA fuel is not significantly different than either the ALS or DF-2 fuel.

Multiple Range Tests for PARTIC by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
5	16	0.161392	X
11	15	0.180949	X
6	15	0.227259	X
10	16	0.252179	X

Contrast	Difference	+/- Limits
5 - 6	*-0.0658665	0.0274018
5 - 10	*-0.0907872	0.0269563
5 - 11	-0.0195566	0.0274018
6 - 10	-0.0249207	0.0274018
6 - 11	*0.04631	0.0278403
10 - 11	*0.0712306	0.0274018

* denotes a statistically significant difference.

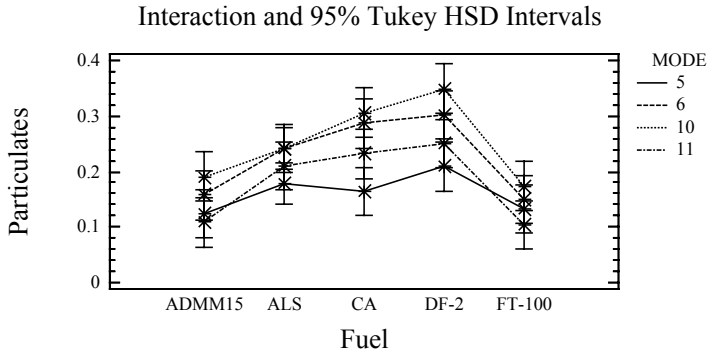
Multiple Range Tests for PARTIC by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	0.13969	X
ADMM15	12	0.145389	X
ALS	14	0.217693	X
CA	12	0.247083	XX
DF-2	12	0.277368	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.0723034	0.0319542
ADMM15 - CA	*-0.101694	0.0331604
ADMM15 - DF-2	*-0.131979	0.0331604
ADMM15 - FT-100	0.00569934	0.0331604
ALS - CA	-0.0293907	0.0319542
ALS - DF-2	*-0.0596755	0.0319542
ALS - FT-100	*0.0780028	0.0319542
CA - DF-2	-0.0302847	0.0331604
CA - FT-100	*0.107394	0.0331604
DF-2 - FT-100	*0.137678	0.0331604

* denotes a statistically significant difference.



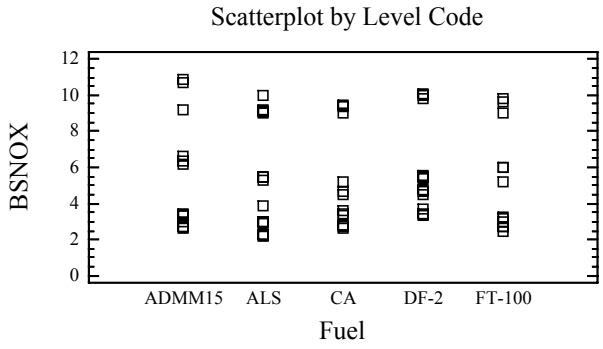
CONCLUSION: The CA and DF-2 fuels have significantly different average particulate at Modes 5 and 11 than at modes 6 and 10. All other fuels do not demonstrate significant differences in the average particulate among the four modes.

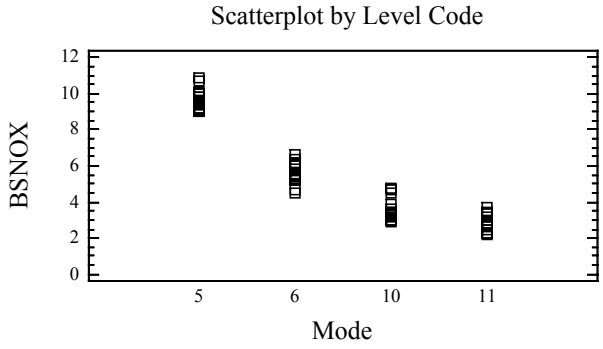
Multifactor ANOVA - BSNOX (g/kW-hr)
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: BSNOX
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



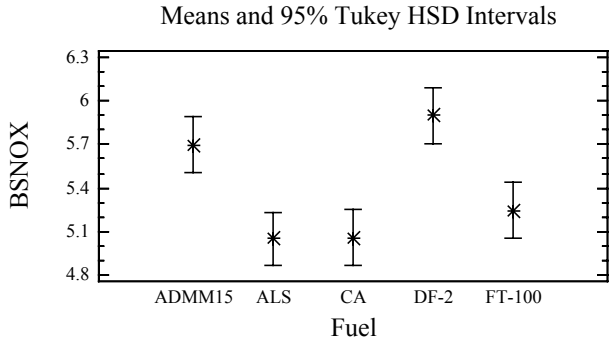


Analysis of Variance for BSNOX - Type III Sums of Squares

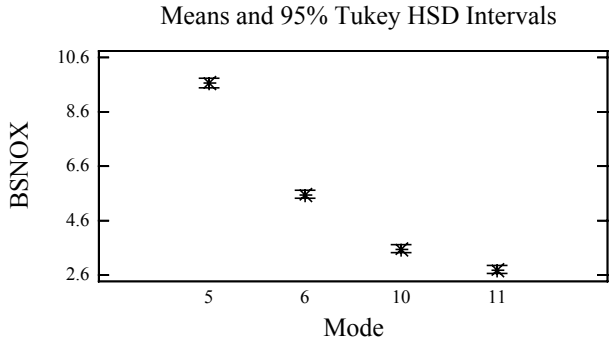
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	7.45754	4	1.86438	16.79	0.0000
B:MODE	443.319	3	147.773	1330.52	0.0000
INTERACTIONS					
AB	6.14855	12	0.512379	4.61	0.0001
RESIDUAL	4.66468	42	0.111064		
TOTAL (CORRECTED)	464.749	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSNOX among the fuels, modes, and fuel*mode interaction.



CONCLUSION: There are two distinct fuel groupings with respect to the average BSNOX. ADMM15 and DF-2 fuels are not significantly different from one another, but are different from the average BSNOX for the ALS, CA, and FT-100 fuels. The ALS, CA, and FT-100 fuels are not significantly different from one another.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSNOX.

Multiple Range Tests for BSNOX by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ALS	14	5.04671	X
CA	12	5.05677	X
FT-100	12	5.24116	X
ADMM15	12	5.69599	X
DF-2	12	5.9005	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*0.649278	0.373652
ADMM15 - CA	*0.63922	0.387757
ADMM15 - DF-2	-0.204506	0.387757
ADMM15 - FT-100	*0.45483	0.387757
ALS - CA	-0.0100577	0.373652
ALS - DF-2	*-0.853784	0.373652
ALS - FT-100	-0.194448	0.373652
CA - DF-2	*-0.843726	0.387757
CA - FT-100	-0.184391	0.387757
DF-2 - FT-100	*0.659336	0.387757

* denotes a statistically significant difference.

Multiple Range Tests for BSNOX by MODE

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
11             15        2.77949           X
10             16        3.55572            X
6              15        5.55988              X
5              16        9.65782                X
-------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                    *4.09794             0.32042
5 - 10                                   *6.1021              0.315209
5 - 11                                   *6.87832             0.32042
6 - 10                                   *2.00416             0.32042
6 - 11                                   *2.78039             0.325547
10 - 11                                  *0.776228            0.32042
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
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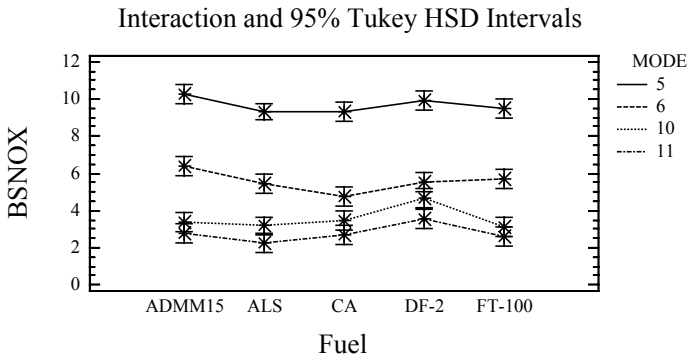
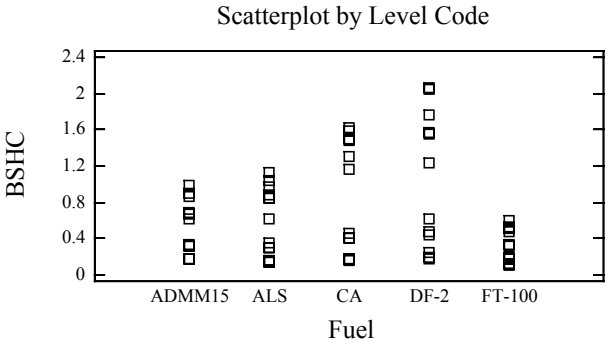


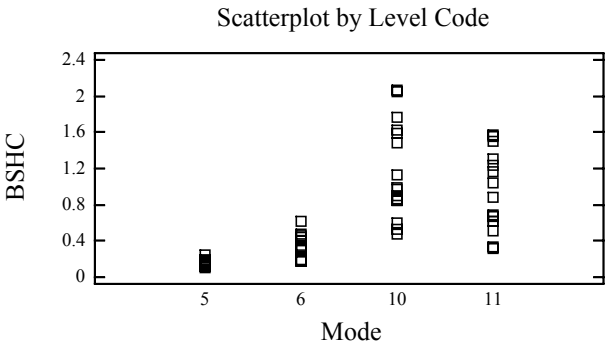
CONCLUSION: While the ADMM15, ALS, CA, and FT-100 fuels all have significant differences in the average BSNOX between mode 6 and modes 10 and 11, the DF-2 fuel does not demonstrate this difference. The average BSNOX among modes 6, 10, and 11 for the DF-2 are not
significantly different from one another.

Multifactor ANOVA - BSHC (g/kW-hr)
LPP Only Modes 5,6,10,11
Analysis Summary

Dependent variable: BSHC
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



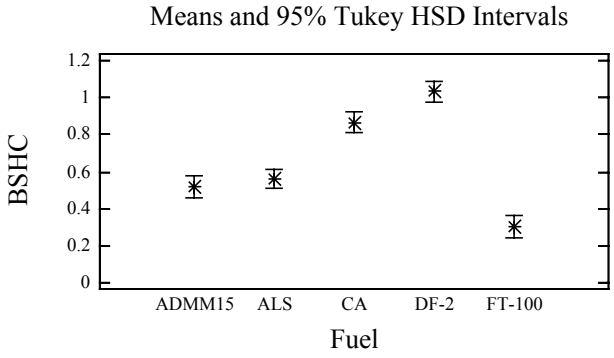


Analysis of Variance for BSHC - Type III Sums of Squares

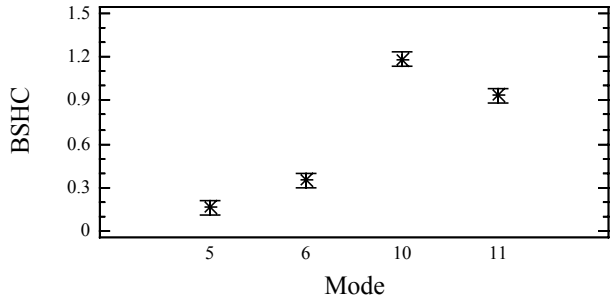
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	4.05731	4	1.01433	104.34	0.0000
B:MODE	10.9203	3	3.64011	374.43	0.0000
INTERACTIONS					
AB	2.4476	12	0.203967	20.98	0.0000
RESIDUAL	0.408308	42	0.00972163		
TOTAL (CORRECTED)	17.7211	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSHC among the fuels, modes, and the fuel*mode interaction.



CONCLUSION: There are four distinct fuel groupings with respect to the average BSHC. FT-100, CA, and DF-2 fuels are all significantly different from one another. Also, fuels ADMM15 and ALS are not significantly different from one another, but they are both significantly different from the other three fuels.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSHC.

Multiple Range Tests for BSHC by FUEL

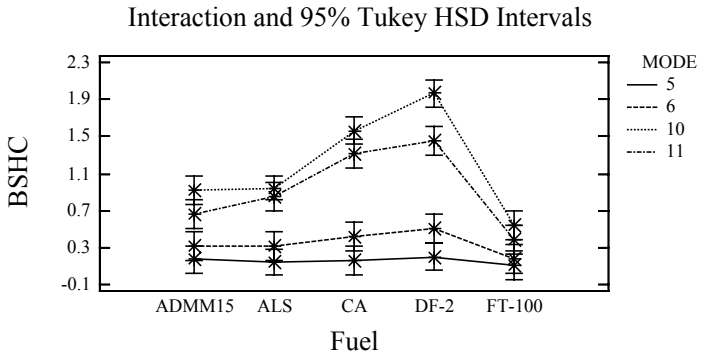
Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	0.302624	X
ADMM15	12	0.519087	X
ALS	14	0.562475	X
CA	12	0.866077	X
DF-2	12	1.03069	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.0433876	0.110548
ADMM15 - CA	*-0.346989	0.114721
ADMM15 - DF-2	*-0.5116	0.114721
ADMM15 - FT-100	*0.216463	0.114721
ALS - CA	*-0.303602	0.110548
ALS - DF-2	*-0.468212	0.110548
ALS - FT-100	*0.259851	0.110548
CA - DF-2	*-0.16461	0.114721
CA - FT-100	*0.563453	0.114721
DF-2 - FT-100	*0.728063	0.114721

* denotes a statistically significant difference.

Multiple Range Tests for BSHC by MODE

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
5              16        0.158889          X
6              15        0.346341           X
11             15        0.934782             X
10             16        1.18475                X
-------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                    *-0.187453           0.0947987
5 - 10                                   *-1.02586            0.0932572
5 - 11                                   *-0.775893           0.0947987
6 - 10                                   *-0.838407           0.0947987
6 - 11                                   *-0.58844            0.0963156
10 - 11                                  *0.249966            0.0947987
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



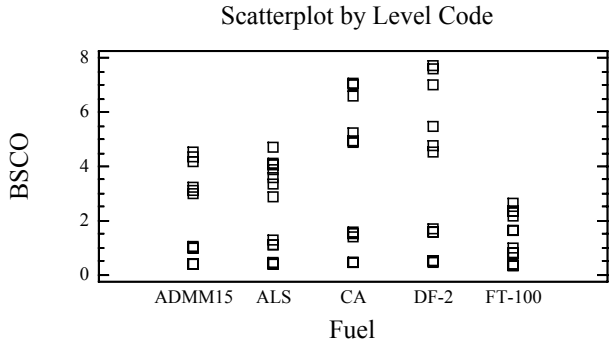
CONCLUSION: The ALS, CA, DF-2 fuels have significantly different average BSHC at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average BSHC among the four modes.

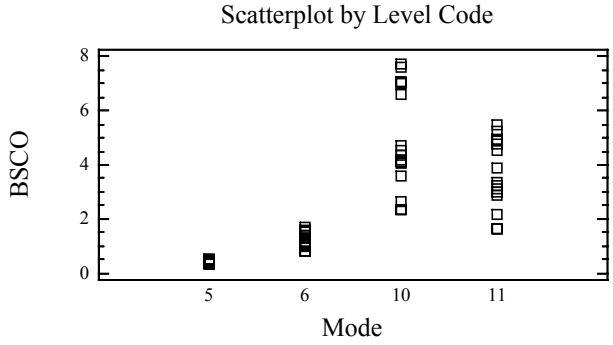
Multifactor ANOVA - BSCO (g/kW-hr)
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: BSCO
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



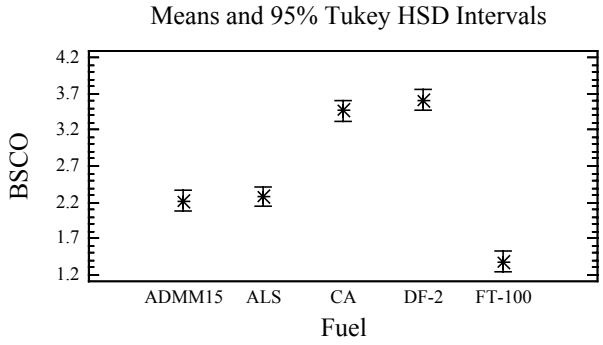


Analysis of Variance for BSCO - Type III Sums of Squares

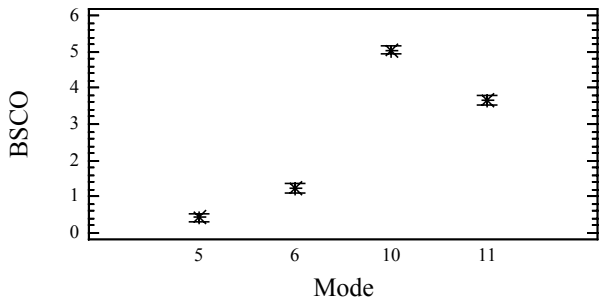
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	42.4521	4	10.613	178.05	0.0000
B:MODE	214.449	3	71.4832	1199.21	0.0000
INTERACTIONS					
AB	33.0659	12	2.7555	46.23	0.0000
RESIDUAL	2.50355	42	0.0596084		
TOTAL (CORRECTED)	290.354	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSCO among the fuels, modes, and fuel*mode interaction.



CONCLUSION: There are three distinct fuel groupings with respect to the average BSCO. FT-100 is significantly different from the other four fuels. ADMM15 and ALS are not significantly different from one another. Fuels CA and DF-2 are not significantly different from one another, but are significantly different from the ADMM15 and ALS fuels.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSCO.

Multiple Range Tests for BSCO by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	1.38081	X
ADMM15	12	2.21783	X
ALS	14	2.27253	X
CA	12	3.46699	X
DF-2	12	3.61618	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.0547025	0.273738
ADMM15 - CA	*-1.24916	0.284071
ADMM15 - DF-2	*-1.39835	0.284071
ADMM15 - FT-100	*0.837021	0.284071
ALS - CA	*-1.19446	0.273738
ALS - DF-2	*-1.34365	0.273738
ALS - FT-100	*0.891724	0.273738
CA - DF-2	-0.149189	0.284071
CA - FT-100	*2.08618	0.284071
DF-2 - FT-100	*2.23537	0.284071

* denotes a statistically significant difference.

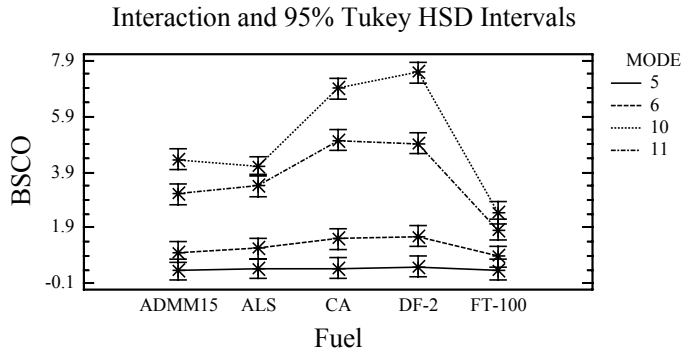
Multiple Range Tests for BSCO by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	0.426311	X
6	15	1.22936	X
11	15	3.65545	X
10	16	5.05234	X

Contrast	Difference	+/- Limits
5 - 6	*-0.803049	0.23474
5 - 10	*-4.62603	0.230923
5 - 11	*-3.22914	0.23474
6 - 10	*-3.82299	0.23474
6 - 11	*-2.42609	0.238496
10 - 11	*1.3969	0.23474

* denotes a statistically significant difference.



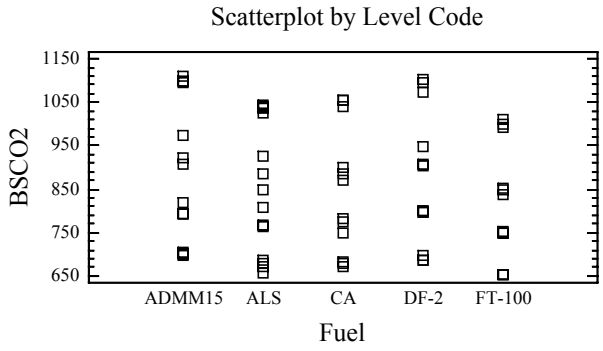
CONCLUSION: The CA, DF-2, and FT-100 fuels have significantly different average BSCO at modes 10 and 11 than at modes 5 and 6.

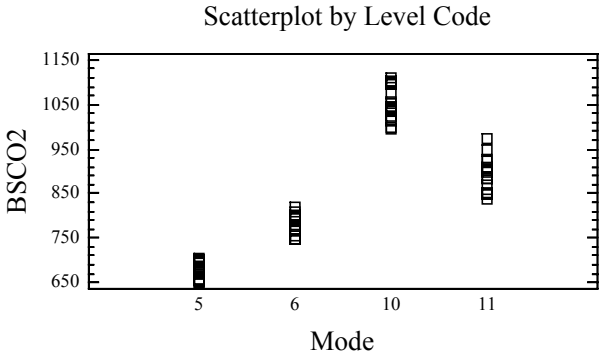
Multifactor ANOVA - BSCO2 (g/kW-hr)
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: BSCO2
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



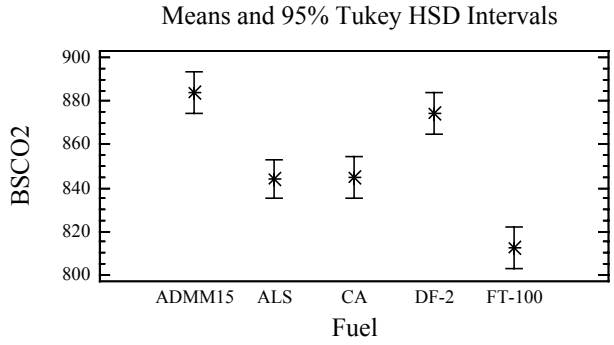


Analysis of Variance for BSCO2 - Type III Sums of Squares

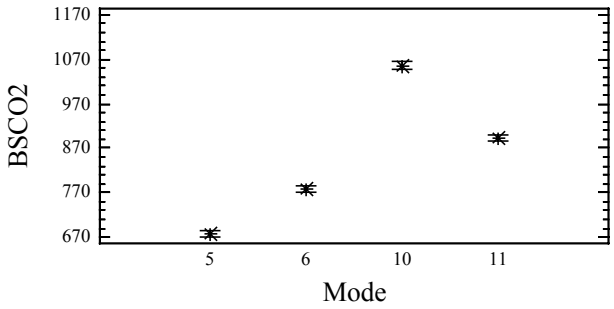
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	38712.5	4	9678.13	36.18	0.0000
B:MODE	1.23777E6	3	412592.0	1542.24	0.0000
INTERACTIONS					
AB	4961.4	12	413.45	1.55	0.1463
RESIDUAL	11236.1	42	267.527		
TOTAL (CORRECTED)	1.30255E6	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSCO2 among the fuels and the modes.



CONCLUSION: There are three distinct fuel groupings with respect to the average BSCO2. FT-100 is significantly different from the other four fuels. ADMM15 and DF-2 fuels are not significantly different from one another. Fuels ALS and CA are not significantly different from one another, but are significantly different from the ADMM15 and DF-2 fuels.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSCO2.

Multiple Range Tests for BSCO2 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	812.402	X
ALS	14	843.98	X
CA	12	844.665	X
DF-2	12	874.424	X
ADMM15	12	884.069	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*40.0882	18.3385
ADMM15 - CA	*39.4037	19.0308
ADMM15 - DF-2	9.64418	19.0308
ADMM15 - FT-100	*71.6664	19.0308
ALS - CA	-0.68448	18.3385
ALS - DF-2	*-30.444	18.3385
ALS - FT-100	*31.5783	18.3385
CA - DF-2	*-29.7595	19.0308
CA - FT-100	*32.2628	19.0308
DF-2 - FT-100	*62.0223	19.0308

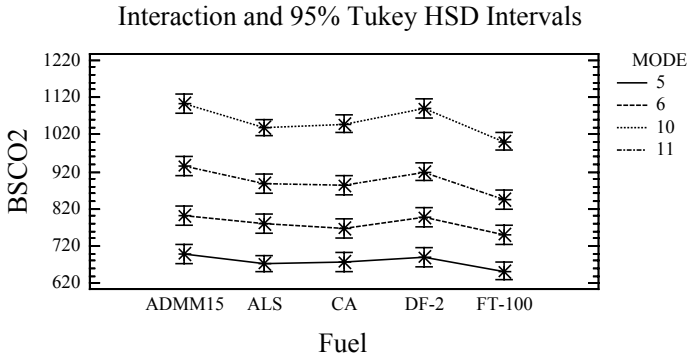
* denotes a statistically significant difference.

Multiple Range Tests for BSCO2 by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
5	16	678.385	X
6	15	779.339	X
11	15	894.059	X
10	16	1055.85	X

Contrast	Difference	+/- Limits
5 - 6	*-100.954	15.7259
5 - 10	*-377.464	15.4702
5 - 11	*-215.674	15.7259
6 - 10	*-276.51	15.7259
6 - 11	*-114.72	15.9776
10 - 11	*161.79	15.7259

* denotes a statistically significant difference.



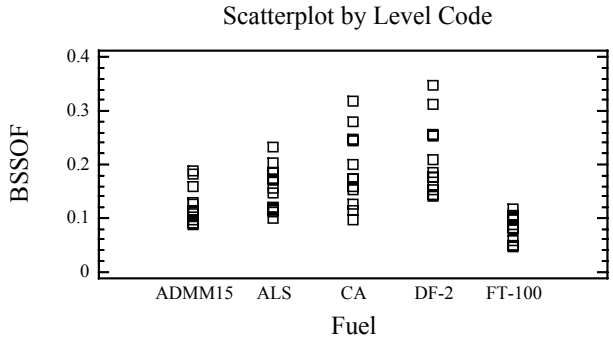
CONCLUSION: No significant differences among the fuel and mode combinations with respect to the average BSCO2.

Multifactor ANOVA - BSSOF (g/kW-hr)
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: bssof
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 61

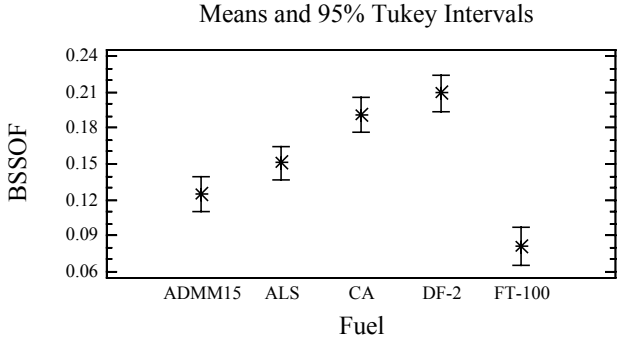


Analysis of Variance for bssof - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.119091	4	0.0297726	47.06	0.0000
B:mode	0.0867779	3	0.028926	45.73	0.0000
INTERACTIONS					
AB	0.0319369	12	0.0026614	4.21	0.0003
RESIDUAL	0.025936	41	0.000632586		
TOTAL (CORRECTED)	0.25938	60			

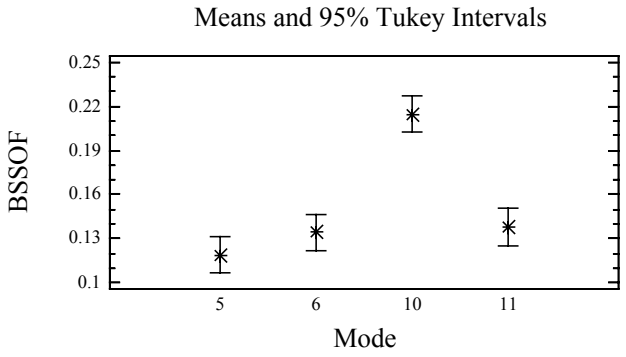
All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSSOF among the fuels, modes, and fuel*mode interaction.



CONCLUSION: There are three distinct fuel groupings with respect to the average

BSSOF. The FT-100 fuel is significantly different from the remaining four fuels. The DF-2 and CA fuels are not significantly different from one another, but are different from the other three fuels. Also, the ALS and ADMM15 fuels are not significantly different from one another, but are different from the other three fuels.



CONCLUSION: The average BSSOF for mode 10 is significantly different from the remaining three modes. The average BSSOF for modes 5, 6, and 11 are not significantly different from one another.

Multiple Range Tests for bssof by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
FT-100	11	0.0812057	X
ADMM15	12	0.125126	X
ALS	14	0.151043	X
CA	12	0.190591	X
DF-2	12	0.209108	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.0259175	0.0282299
ADMM15 - CA	*-0.0654649	0.0292956
ADMM15 - DF-2	*-0.0839822	0.0292956
ADMM15 - FT-100	*0.04392	0.029954
ALS - CA	*-0.0395474	0.0282299
ALS - DF-2	*-0.0580647	0.0282299
ALS - FT-100	*0.0698376	0.0289126
CA - DF-2	-0.0185173	0.0292956
CA - FT-100	*0.109385	0.029954
DF-2 - FT-100	*0.127902	0.029954

* denotes a statistically significant difference.

Multiple Range Tests for bssof by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups
5	16	0.118924	X
6	15	0.13431	X
11	14	0.137743	X
10	16	0.214683	X

Contrast	Difference	+/- Limits
5 - 6	-0.0153858	0.0242062
5 - 10	*-0.0957587	0.0238126

```
5 - 11                                  -0.0188186          0.0246484
6 - 10                                 *-0.0803729          0.0242062
6 - 11                                  -0.00343286         0.0250289
10 - 11                                *0.0769401           0.0246484
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
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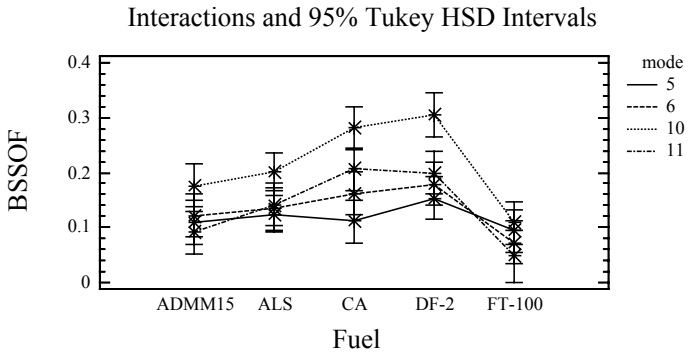


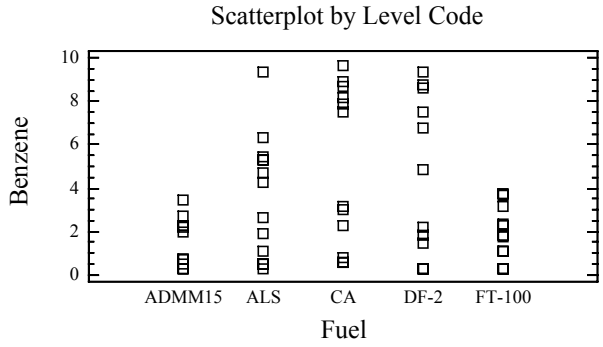
CONCLUSION: The trend in the average BSSOF across the fuels is different for mode 10 at the CA and DF-2 fuels. The trends in the average BSSOF across the fuels for modes 5, 6, and 11 do not appear to be different.

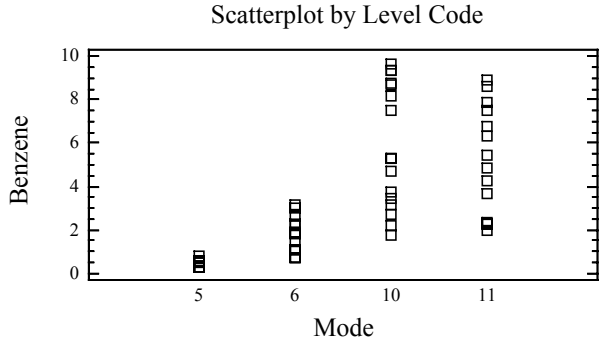
Multifactor ANOVA - BENZENE (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: BENZENE
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



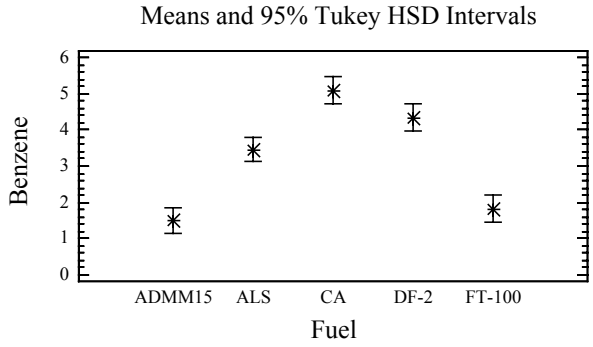


Analysis of Variance for BENZENE - Type III Sums of Squares

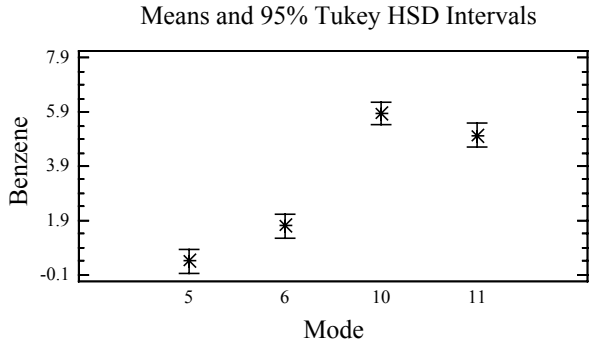
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	117.444	4	29.361	36.42	0.0000
B:MODE	318.024	3	106.008	131.48	0.0000
INTERACTIONS					
AB	71.702	12	5.97517	7.41	0.0000
RESIDUAL	33.8638	42	0.806281		
TOTAL (CORRECTED)	545.5	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average benzene for the ADMM15 and FT-100 fuels are not significantly different from one another, but are significantly different from the remaining three fuels. The average benzene for the ALS fuel is significantly different than the average benzene for the CA fuel.



CONCLUSION: There are three distinct mode groupings with respect to the average benzene. Modes 10 and 11 are not significantly different from one another, but are significantly different than the other two modes. Modes 5 and 6 are significantly different from one another and the other two modes.

Multiple Range Tests for BENZENE by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	12	1.50136	X
FT-100	12	1.81143	X
ALS	14	3.45994	X
DF-2	12	4.34774	XX
CA	12	5.0951	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-1.95858	1.00676
ADMM15 - CA	*-3.59373	1.04476
ADMM15 - DF-2	*-2.84638	1.04476
ADMM15 - FT-100	-0.310068	1.04476
ALS - CA	*-1.63515	1.00676
ALS - DF-2	-0.8878	1.00676
ALS - FT-100	*1.64851	1.00676
CA - DF-2	0.747355	1.04476
CA - FT-100	*3.28366	1.04476
DF-2 - FT-100	*2.53631	1.04476

* denotes a statistically significant difference.

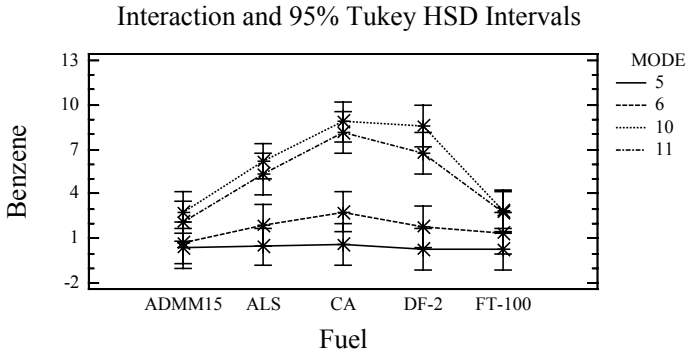
Multiple Range Tests for BENZENE by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	0.392344	X
6	15	1.70996	X
11	15	5.02793	X
10	16	5.84222	X

Contrast	Difference	+/- Limits
5 - 6	*-1.31762	0.863329
5 - 10	*-5.44988	0.84929
5 - 11	*-4.63559	0.863329
6 - 10	*-4.13226	0.863329
6 - 11	*-3.31797	0.877143
10 - 11	0.814288	0.863329

* denotes a statistically significant difference.



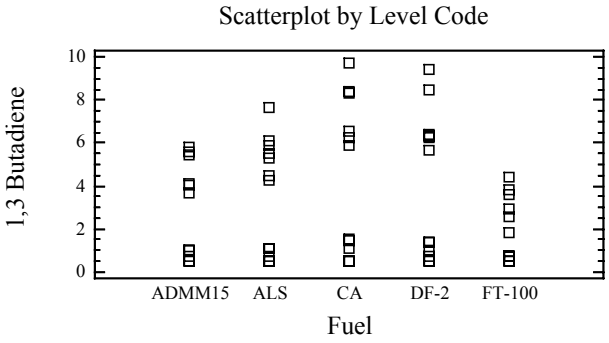
CONCLUSION: The ALS, CA, and DF-2 fuels have significantly different average benzene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average benzene among the four modes.

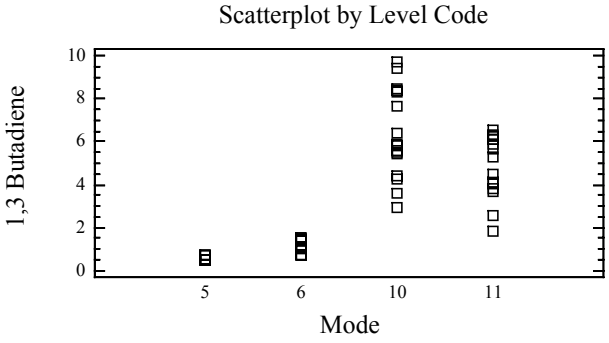
Multifactor ANOVA - 1,3 Butadiene (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: BUTAD
Factors:
MODE
FUEL
Selection variable: MODE<12

Number of complete cases: 62



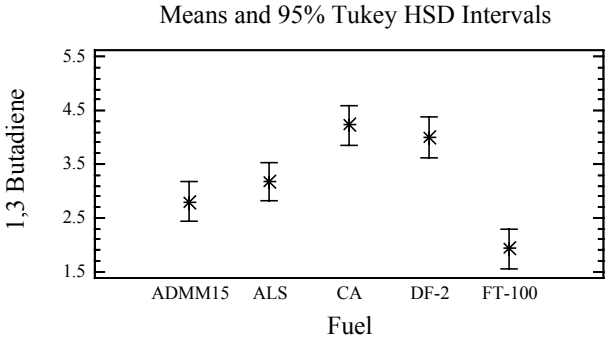


Analysis of Variance for BUTAD - Type III Sums of Squares

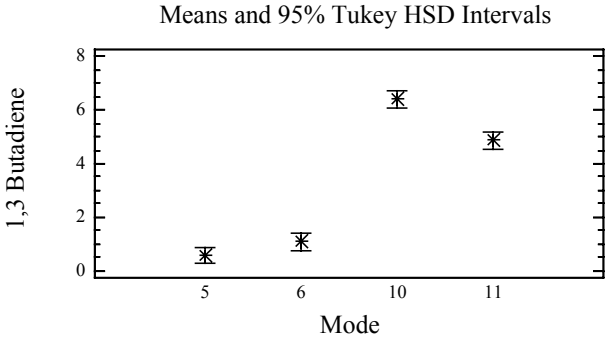
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MODE	379.258	3	126.419	304.67	0.0000
B:FUEL	41.8936	4	10.4734	25.24	0.0000
INTERACTIONS					
AB	36.8996	12	3.07497	7.41	0.0000
RESIDUAL	17.4272	42	0.414933		
TOTAL (CORRECTED)	475.499	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average 1,3 butadiene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: There are three distinct fuel groupings with respect to the average 1,3 butadiene.
The average 1,3 butadiene for the FT-100 fuel is significantly different than the remaining
four fuels. The ADMM15 and ALS fuels are not significantly different from one another, but
are significantly different than the other three fuels. Also, the DF-2 and CA fuels are not significantly different from one another, but are significantly different from the other three fuels.



CONCLUSION: There are three distinct mode groupings with respect to the average 1,3 butadiene. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another but are significantly different from the other two modes.

Multiple Range Tests for BUTAD by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	1.92136	X
ADMM15	12	2.79864	X
ALS	14	3.18606	X
DF-2	12	3.99958	X
CA	12	4.22908	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.387414	0.722221
ADMM15 - CA	*-1.43044	0.749484
ADMM15 - DF-2	*-1.20094	0.749484
ADMM15 - FT-100	*0.877277	0.749484
ALS - CA	*-1.04303	0.722221
ALS - DF-2	*-0.813527	0.722221
ALS - FT-100	*1.26469	0.722221

CA - DF-2	0.229499	0.749484
CA - FT-100	*2.30772	0.749484
DF-2 - FT-100	*2.07822	0.749484

* denotes a statistically significant difference.

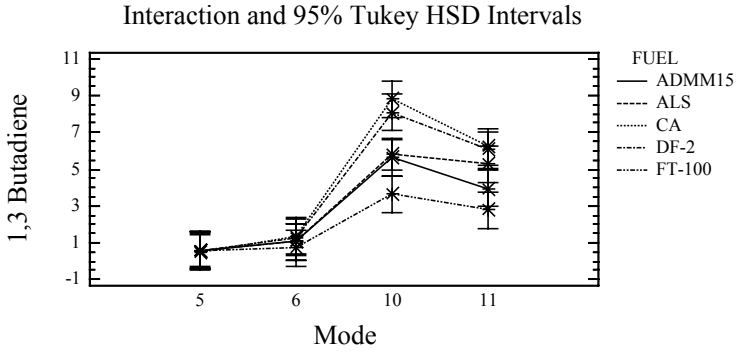
Multiple Range Tests for BUTAD by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	0.560078	X
6	15	1.09161	X
11	15	4.86034	X
10	16	6.39576	X

Contrast	Difference	+/- Limits
5 - 6	-0.531529	0.61933
5 - 10	*-5.83568	0.609259
5 - 11	*-4.30026	0.61933
6 - 10	*-5.30415	0.61933
6 - 11	*-3.76873	0.62924
10 - 11	*1.53542	0.61933

* denotes a statistically significant difference.



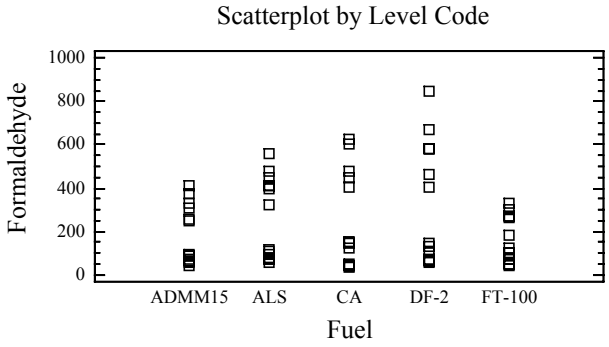
CONCLUSION: The DF-2 and CA fuels have significantly different average 1,3 butadiene at mode 10 than at the remaining three modes. All other fuels do not demonstrate significant differences in the average 1,3 butadiene among the four modes.

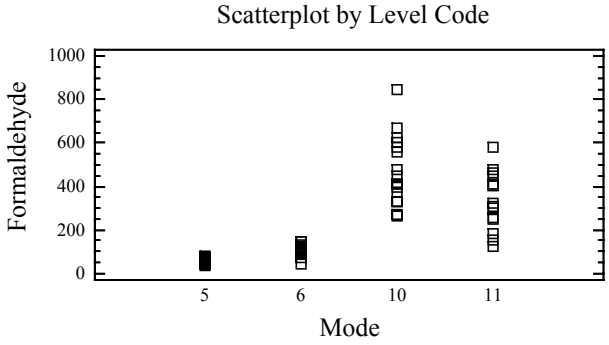
Multifactor ANOVA - Formaldehyde (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: FORMALD
Factors:
MODE
FUEL
Selection variable: MODE<12

Number of complete cases: 61



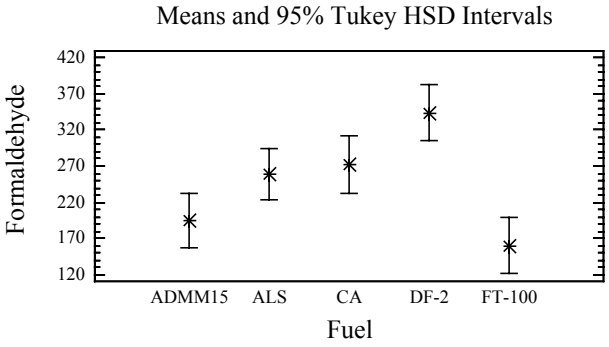


Analysis of Variance for FORMALD - Type III Sums of Squares

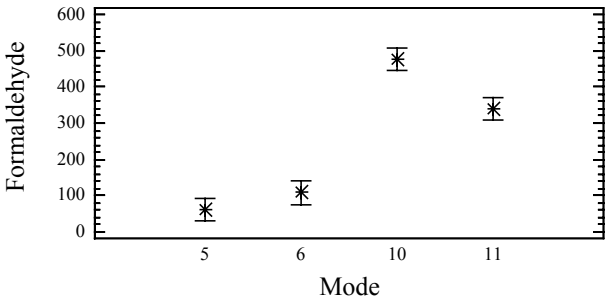
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MODE	1.78043E6	3	593477.0	140.26	0.0000
B:FUEL	243068.0	4	60766.9	14.36	0.0000
INTERACTIONS					
AB	226880.0	12	18906.7	4.47	0.0001
RESIDUAL	173482.0	41	4231.27		
TOTAL (CORRECTED)	2.44233E6	60			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average formaldehyde among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average formaldehyde for the DF-2 fuel is not significantly different than the average formaldehyde for the CA fuel, but it is significantly different than the ADMM15, FT-100, and ALS fuels. The average formaldehyde at the FT-100 fuel is not significantly different than the ADMM15 fuel, but it is significantly different than the ALS, CA, and DF-2 fuels.



CONCLUSION: There are three distinct mode groupings with respect to the average formaldehyde. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another but are significantly different from the other two modes.

Multiple Range Tests for FORMALD by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	160.347	X
ADMM15	12	195.548	XX
ALS	14	258.61	X
CA	11	271.78	XX
DF-2	12	343.987	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-63.0621	73.0105
ADMM15 - CA	-76.2323	77.4694
ADMM15 - DF-2	*-148.439	75.7666
ADMM15 - FT-100	35.2004	75.7666
ALS - CA	-13.1703	74.7761
ALS - DF-2	*-85.3773	73.0105
ALS - FT-100	*98.2624	73.0105
CA - DF-2	-72.207	77.4694
CA - FT-100	*111.433	77.4694
DF-2 - FT-100	*183.64	75.7666

* denotes a statistically significant difference.

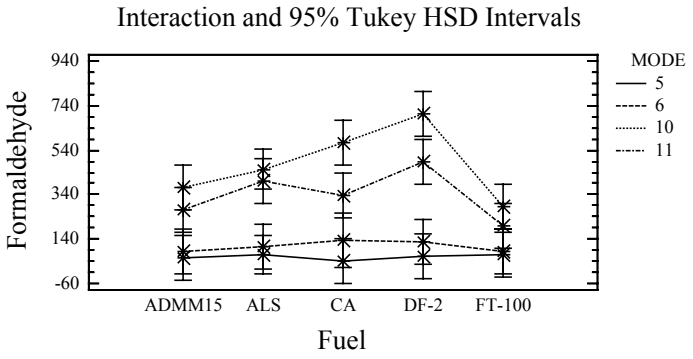
Multiple Range Tests for FORMALD by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	59.7879	X
6	14	107.775	X
11	15	339.847	X
10	16	476.807	X

Contrast	Difference	+/- Limits
5 - 6	-47.9867	63.7477
5 - 10	*-417.02	61.5861
5 - 11	*-280.059	62.6041
6 - 10	*-369.033	63.7477
6 - 11	*-232.073	64.7317
10 - 11	*136.96	62.6041

* denotes a statistically significant difference.



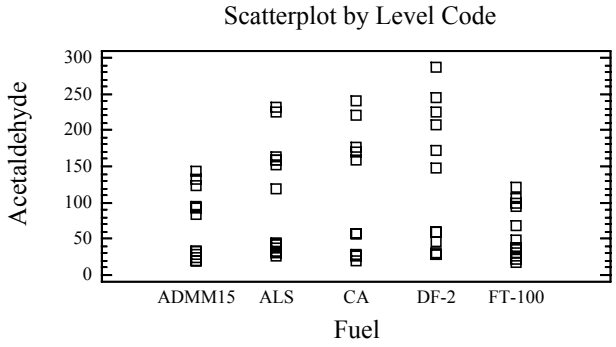
CONCLUSION: The ALS and DF-2 fuels have significantly different average formaldehyde at modes 10 and 11 than at the remaining two modes. All other fuels do not demonstrate this difference. However, the average formaldehyde for the CA fuel at mode 10 is significantly different than the other three modes.

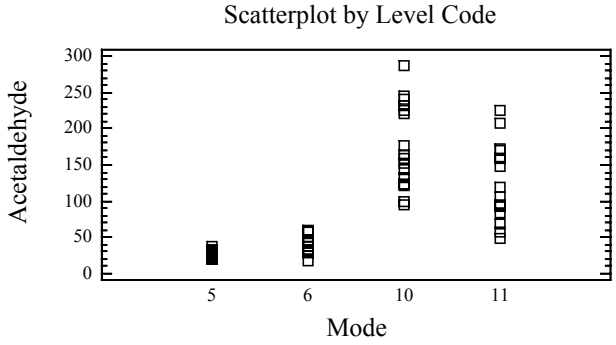
Multifactor ANOVA - Acetaldehyde (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: ACETALD
Factors:
MODE
FUEL
Selection variable: MODE<12

Number of complete cases: 61



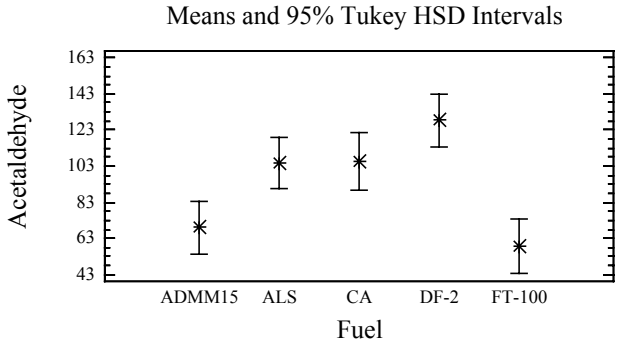


Analysis of Variance for ACETALD - Type III Sums of Squares

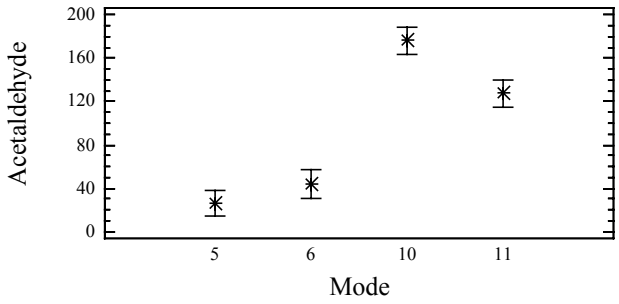
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MODE	229776.0	3	76591.9	117.33	0.0000
B:FUEL	39603.9	4	9900.99	15.17	0.0000
INTERACTIONS					
AB	30463.6	12	2538.64	3.89	0.0005
RESIDUAL	26765.0	41	652.805		
TOTAL (CORRECTED)	330272.0	60			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average acetaldehyde among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average acetaldehyde for the FT-100 and ADMM15 fuels are not significantly different from one another. The average acetaldehyde for the ALS, CA, and DF-2 fuels are not significantly different from one another, but are significantly different from the FT-100 and ADMM15 fuels.



CONCLUSION: There are three distinct mode groupings with respect to the average acetaldehyde. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another but are significantly different from the other two modes.

Multiple Range Tests for ACETALD by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	58.6822	X
ADMM15	12	69.034	X
ALS	14	104.807	X
CA	11	105.591	X
DF-2	12	128.336	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-35.773	28.6775
ADMM15 - CA	*-36.5574	30.4289
ADMM15 - DF-2	*-59.3016	29.7601
ADMM15 - FT-100	10.3518	29.7601
ALS - CA	-0.784358	29.371
ALS - DF-2	-23.5285	28.6775
ALS - FT-100	*46.1248	28.6775
CA - DF-2	-22.7442	30.4289
CA - FT-100	*46.9092	30.4289
DF-2 - FT-100	*69.6533	29.7601

* denotes a statistically significant difference.

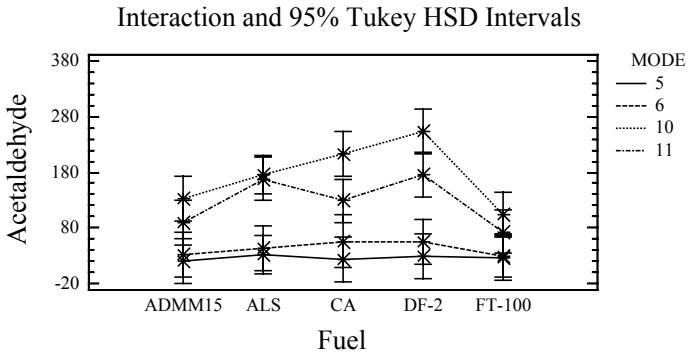
Multiple Range Tests for ACETALD by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	26.3907	X
6	14	43.4665	X
11	15	127.304	X
10	16	175.999	X

Contrast	Difference	+/- Limits
5 - 6	-17.0759	25.0392
5 - 10	*-149.608	24.1902
5 - 11	*-100.913	24.59
6 - 10	*-132.532	25.0392
6 - 11	*-83.8375	25.4257
10 - 11	*48.6949	24.59

* denotes a statistically significant difference.



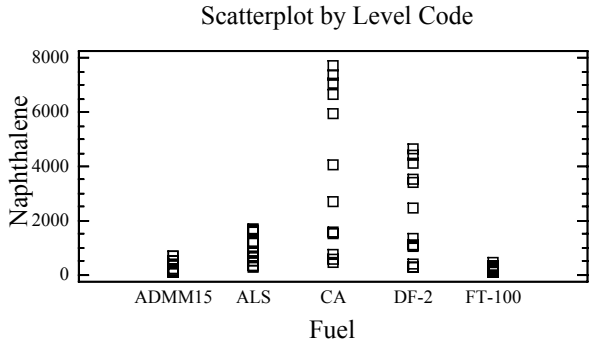
CONCLUSION: The ALS and DF-2 fuels have significantly different average acetaldehyde at modes 10 and 11 than at the remaining two modes. All other fuels do not demonstrate this difference. However, the average acetaldehyde for the CA fuel at mode 10 is significantly different than the other three modes.

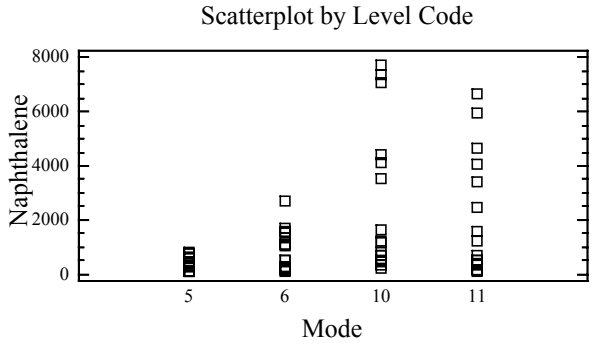
Multifactor ANOVA - NAPHTHALENE (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: GNAPHTH
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



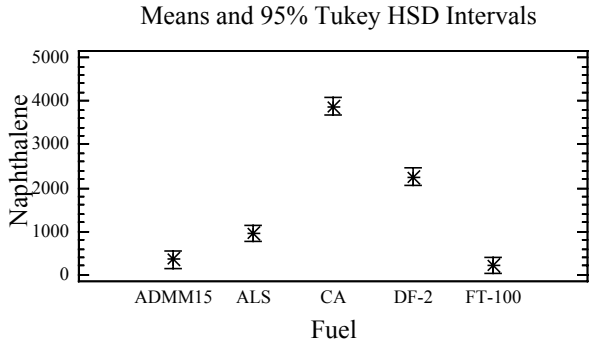


Analysis of Variance for GNAPHTH - Type III Sums of Squares

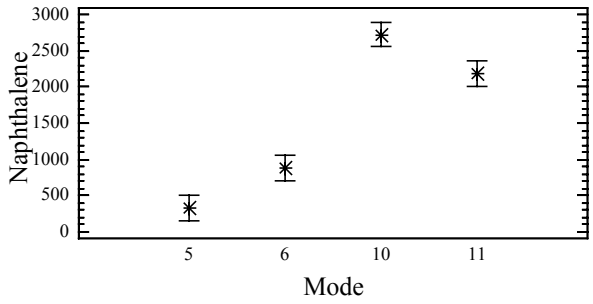
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1.14822E8	4	2.87056E7	127.16	0.0000
B:MODE	5.84374E7	3	1.94791E7	86.29	0.0000
INTERACTIONS					
AB	6.52183E7	12	5.43486E6	24.08	0.0000
RESIDUAL	9.48109E6	42	225740.0		
TOTAL (CORRECTED)	2.44846E8	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average naphthalene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: There are four distinct fuel groupings with respect to the average naphthalene. ALS, DF-2, and CA fuels are all significantly different from one another. Also, fuels ADMM15 and FT-100 are not significantly different from one another, but they are both significantly different from the other three fuels.



CONCLUSION: All four modes are significantly different from one another with respect to the average naphthalene.

Multiple Range Tests for GNAPHTH by FUEL

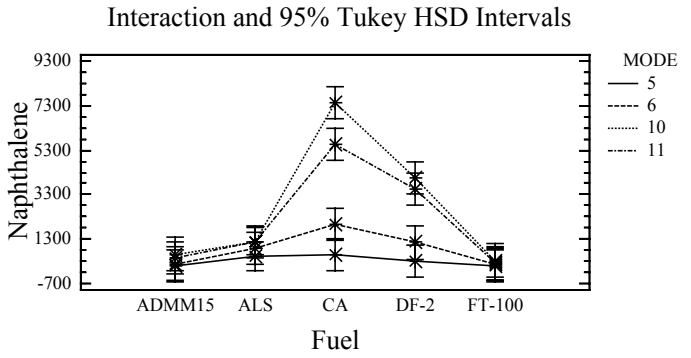
Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	211.807	X
ADMM15	12	352.674	X
ALS	14	950.021	X
DF-2	12	2259.44	X
CA	12	3881.48	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-597.347	532.703
ADMM15 - CA	*-3528.81	552.812
ADMM15 - DF-2	*-1906.76	552.812
ADMM15 - FT-100	140.867	552.812
ALS - CA	*-2931.46	532.703
ALS - DF-2	*-1309.41	532.703
ALS - FT-100	*738.214	532.703
CA - DF-2	*1622.05	552.812
CA - FT-100	*3669.67	552.812
DF-2 - FT-100	*2047.63	552.812

* denotes a statistically significant difference.

Multiple Range Tests for GNAPHTH by MODE

```
------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE            Count     LS Mean           Homogeneous Groups
------------------------------------------------------------------------------
5               16        323.13            X
6               15        883.544            X
11              15        2190.63              X
10              16        2727.03                X
------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
------------------------------------------------------------------------------
5 - 6                                    *-560.415            456.812
5 - 10                                   *-2403.9             449.384
5 - 11                                   *-1867.5             456.812
6 - 10                                   *-1843.48            456.812
6 - 11                                   *-1307.09            464.121
10 - 11                                  *536.397             456.812
------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



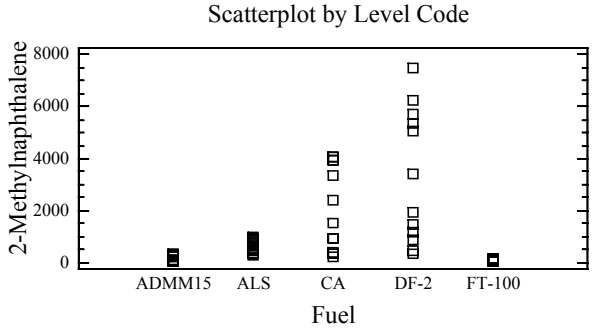
CONCLUSION: The CA and DF-2 fuels have significantly different average naphthalene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average naphthalene among the four modes.

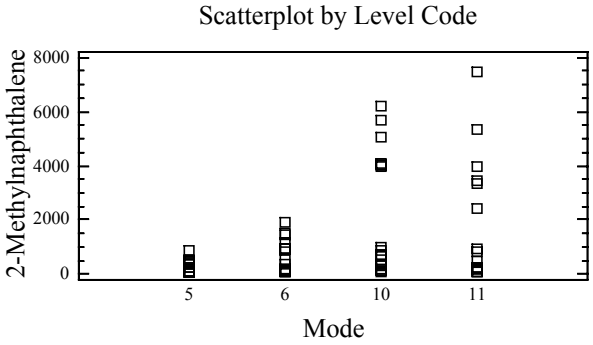
Multifactor ANOVA - 2-Methylnaphthalene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: METHYL2
Factors:
FUEL
MODE
Selection variable: MODE < 12

Number of complete cases: 62



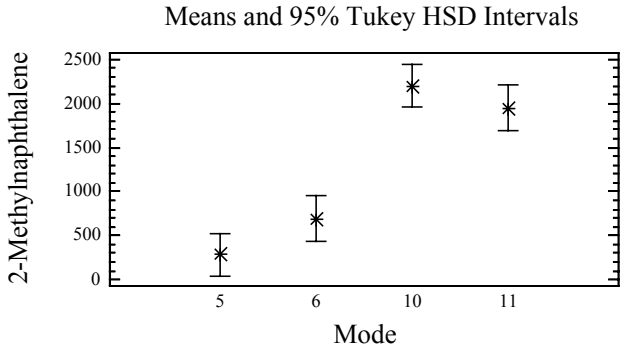


Analysis of Variance for METHYL2 - Type III Sums of Squares

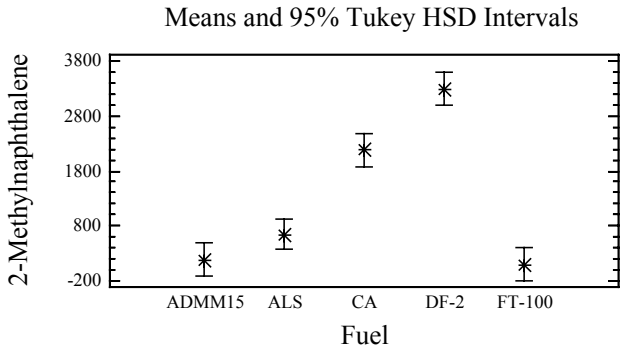
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	9.45452E7	4	2.36363E7	89.10	0.0000
B:MODE	4.08008E7	3	1.36003E7	51.27	0.0000
INTERACTIONS					
AB	5.19123E7	12	4.32603E6	16.31	0.0000
RESIDUAL	1.11418E7	42	265281.0		
TOTAL (CORRECTED)	1.96183E8	61			

All F-ratios are based on the residual mean square error.

Conclusion: Statistically significant differences in the average 2-Methylnaphthalene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: Average 2-methylnaphthalene at Modes 5 and 6 are not significantly different from one another, but significantly different from modes 10 and 11. Modes 10 and 11 are not significantly different from one another with respect to the average 2-methylnaphthalene.



CONCLUSION: Average 2-methylnaphthalene for fuels FT-100, ADMM15, and ALS are not significantly different from one another. The average 2-methylnaphthalene for fuels CA and DF-2 are significantly different from one another.

Multiple Range Tests for METHYL2 by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	282.936	X
6	15	693.966	X
11	15	1948.64	X
10	16	2195.93	X

Contrast	Difference	+/- Limits
5 - 6	-411.03	495.207
5 - 10	*-1912.99	487.154
5 - 11	*-1665.7	495.207
6 - 10	*-1501.96	495.207
6 - 11	*-1254.67	503.13
10 - 11	247.288	495.207

* denotes a statistically significant difference.

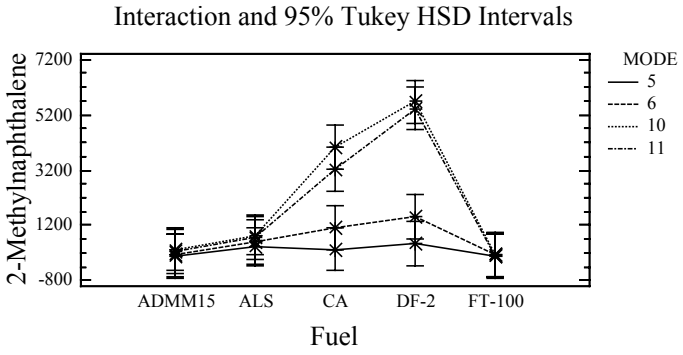
Multiple Range Tests for METHYL2 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	107.033	X
ADMM15	12	183.294	X
ALS	14	646.591	X
CA	12	2173.94	X
DF-2	12	3290.98	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-463.297	577.476
ADMM15 - CA	*-1990.65	599.276
ADMM15 - DF-2	*-3107.68	599.276
ADMM15 - FT-100	76.2607	599.276
ALS - CA	*-1527.35	577.476
ALS - DF-2	*-2644.38	577.476
ALS - FT-100	539.557	577.476
CA - DF-2	*-1117.03	599.276
CA - FT-100	*2066.91	599.276
DF-2 - FT-100	*3183.94	599.276

* denotes a statistically significant difference.



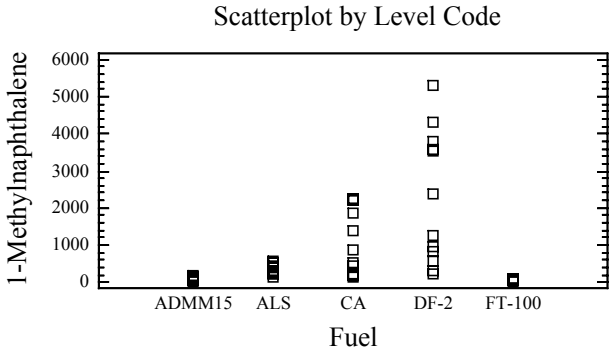
CONCLUSION: Modes 10 and 11 have significantly different average 2-methylnaphthalene for the CA and DF-2 fuels. All other fuels do not demonstrate differences in the average 2-methylnaphthalene among the four modes.

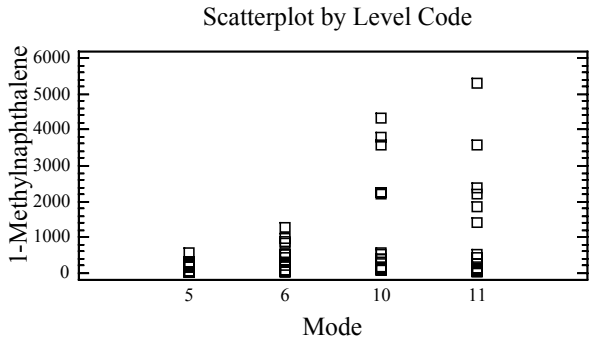
Multifactor ANOVA - 1-Methylnaphthalene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: METHYL1
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



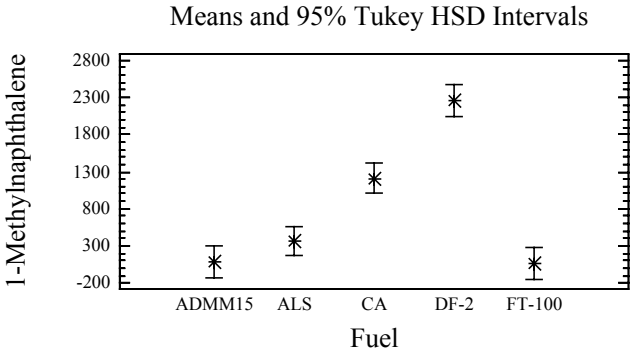


Analysis of Variance for METHYL1 - Type III Sums of Squares

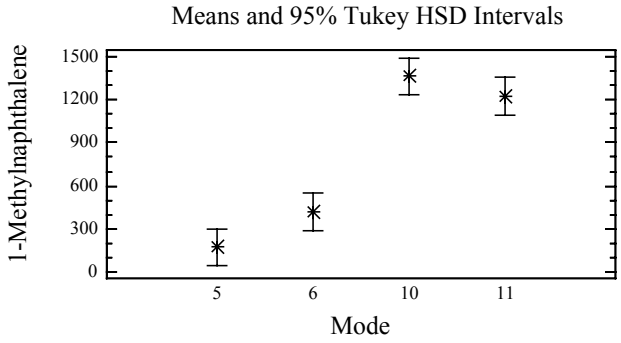
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	4.27538E7	4	1.06885E7	83.75	0.0000
B:MODE	1.61965E7	3	5.39884E6	42.30	0.0000
INTERACTIONS					
AB	2.33649E7	12	1.94707E6	15.26	0.0000
RESIDUAL	5.36042E6	42	127629.0		
TOTAL (CORRECTED)	8.67884E7	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average 1-methylnaphthalene among the fuels, modes and fuel*mode interaction.



CONCLUSION: There were three distinct fuel groupings with respect to the average 1-methylnaphthalene. CA and DF-2 fuels were significantly different from one another and the other three fuels. ADMM15, ALS, and FT-100 fuels were not significantly different from one another.



CONCLUSION: Average 1-methylnaphthalene at modes 5 and 6 are not significantly different from one another. Average 1-methylnaphthalene at modes 10 and 11 are not significantly different from one another, but are significantly different from modes 5 and 6.

Multiple Range Tests for METHYL1 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	61.5376	X
ADMM15	12	86.5013	X
ALS	14	363.927	X
CA	12	1212.87	X
DF-2	12	2256.67	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-277.426	400.549
ADMM15 - CA	*-1126.37	415.669
ADMM15 - DF-2	*-2170.17	415.669
ADMM15 - FT-100	24.9637	415.669
ALS - CA	*-848.947	400.549
ALS - DF-2	*-1892.74	400.549
ALS - FT-100	302.389	400.549
CA - DF-2	*-1043.8	415.669
CA - FT-100	*1151.34	415.669
DF-2 - FT-100	*2195.13	415.669

* denotes a statistically significant difference.

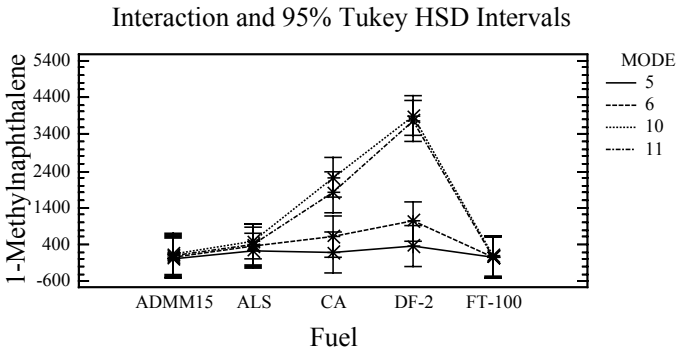
Multiple Range Tests for METHYL1 by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	170.726	X
6	15	421.11	X
11	15	1228.57	X
10	16	1364.8	X

Contrast	Difference	+/- Limits
5 - 6	-250.385	343.485
5 - 10	*-1194.07	337.899
5 - 11	*-1057.85	343.485
6 - 10	*-943.689	343.485
6 - 11	*-807.464	348.981
10 - 11	136.225	343.485

* denotes a statistically significant difference.



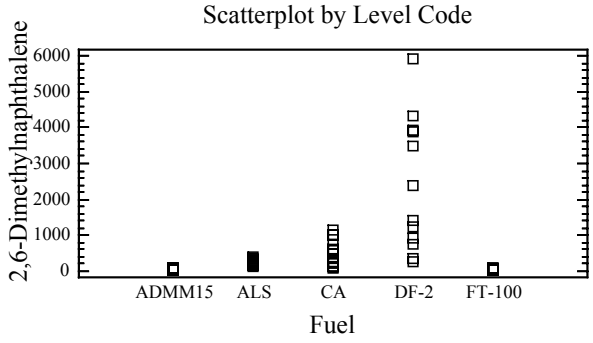
CONCLUSION: The CA and DF-2 fuels have significantly different average 1-methylnaphthalene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average 1-methylnaphthalene among the four modes.

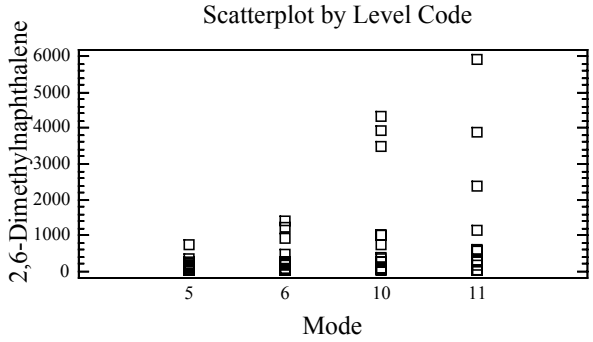
Multifactor ANOVA - 2,6-Dimethylnaphthalene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: DIMETHYL
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



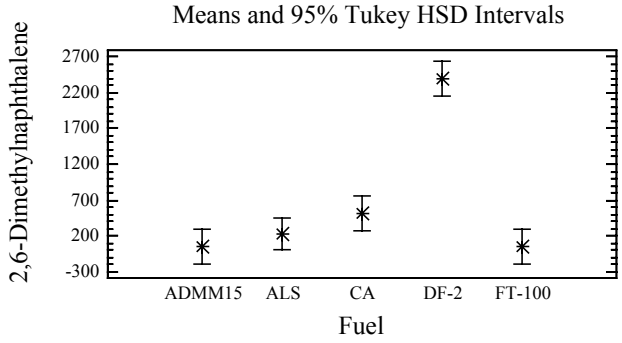


Analysis of Variance for DIMETHYL - Type III Sums of Squares

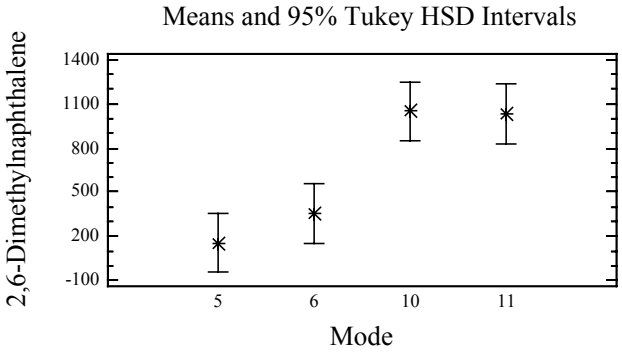
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	4.83445E7	4	1.20861E7	69.59	0.0000
B:MODE	9.92486E6	3	3.30829E6	19.05	0.0000
INTERACTIONS					
AB	2.31461E7	12	1.92884E6	11.11	0.0000
RESIDUAL	7.29431E6	42	173674.0		
TOTAL (CORRECTED)	8.81659E7	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average 2,6-Dimethylnaphthalene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average 2,6-dimethylnaphthalene for the DF-2 fuel is significantly different than the other four fuels. The average 2,6-dimethylnaphthalene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.



CONCLUSION: Average 2,6-dimethylnaphthalene at modes 5 and 6 are not significantly different from one another. Average 2,6-dimethylnaphthalene at modes 10 and 11 are not significantly different from one another, but are significantly different than modes 5 and 6.

Multiple Range Tests for DIMETHYL by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	12	41.3485	X
FT-100	12	43.5168	X
ALS	14	227.587	X
CA	12	522.143	X
DF-2	12	2402.48	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-186.238	467.249
ADMM15 - CA	-480.795	484.887
ADMM15 - DF-2	*-2361.14	484.887
ADMM15 - FT-100	-2.16827	484.887
ALS - CA	-294.556	467.249
ALS - DF-2	*-2174.9	467.249
ALS - FT-100	184.07	467.249
CA - DF-2	*-1880.34	484.887
CA - FT-100	478.626	484.887
DF-2 - FT-100	*2358.97	484.887

* denotes a statistically significant difference.

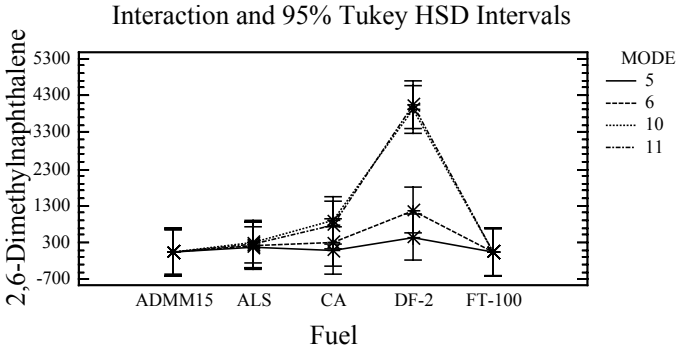
Multiple Range Tests for DIMETHYL by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	152.253	X
6	15	355.65	X
11	15	1030.29	X
10	16	1051.47	X

Contrast	Difference	+/- Limits
5 - 6	-203.396	400.683
5 - 10	*-899.217	394.167
5 - 11	*-878.036	400.683
6 - 10	*-695.821	400.683
6 - 11	*-674.64	407.094
10 - 11	21.1803	400.683

* denotes a statistically significant difference.



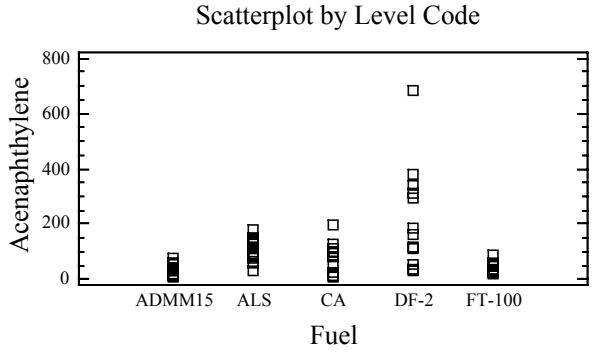
CONCLUSION: The DF-2 fuel has significantly different average 2,6-dimethylnaphthalene at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average 2,6-dimethylnaphthalene among the four modes.

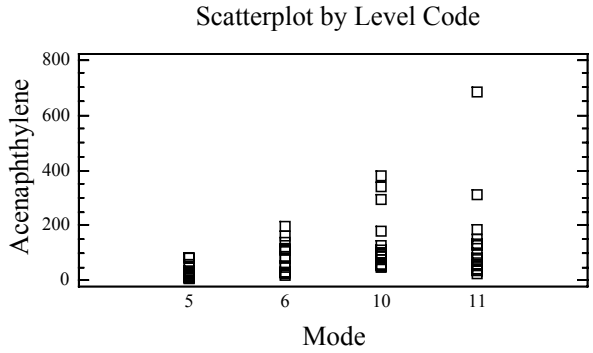
Multifactor ANOVA - Acenaphthylene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: GACENAPH
Factors:
MODE
FUEL
Selection variable: MODE < 12

Number of complete cases: 62



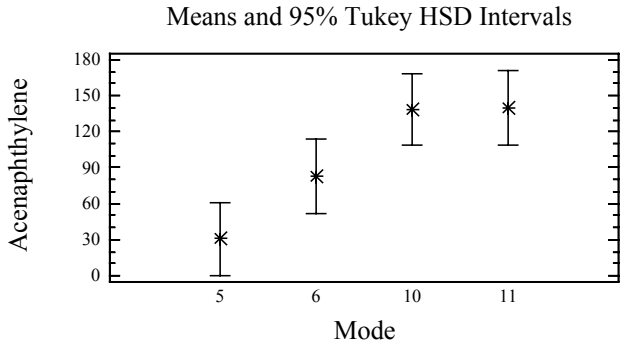


Analysis of Variance for GACENAPH - Type III Sums of Squares

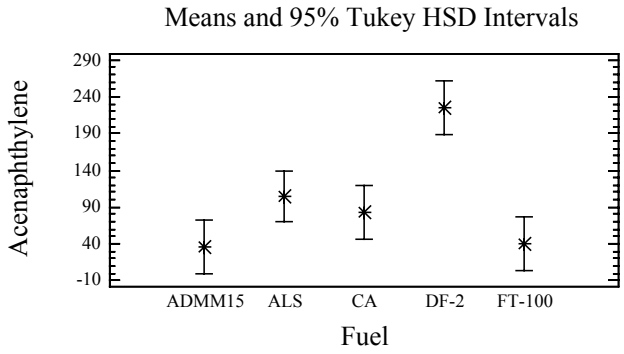
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MODE	126587.0	3	42195.7	10.52	0.0000
B:FUEL	283597.0	4	70899.2	17.68	0.0000
INTERACTIONS					
AB	165392.0	12	13782.6	3.44	0.0014
RESIDUAL	168412.0	42	4009.81		
TOTAL (CORRECTED)	739866.0	61			

All F-ratios are based on the residual mean square error.
Multiple Range Tests for GACENAPH by MODE

CONCLUSION: Statistically significant differences in the average acenaphthylene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: Average acenaphthylene at Mode 5 is significantly different from modes 10 and 11.



CONCLUSION: Average acenaphthylene is significantly different at fuel DF-2 compared to the
other four fuels. Average acenaphthylene at fuels ADMM15, ALS, CA, and FT-100 are not significantly different from one another.

Multiple Range Tests for GACENAPH by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
5	16	30.8267	X
6	15	82.4049	XX
10	16	138.499	X
11	15	139.484	X

Contrast	Difference	+/- Limits
5 - 6	-51.5782	60.8828
5 - 10	*-107.672	59.8928
5 - 11	*-108.657	60.8828
6 - 10	-56.094	60.8828
6 - 11	-57.0787	61.857
10 - 11	-0.984737	60.8828

* denotes a statistically significant difference.

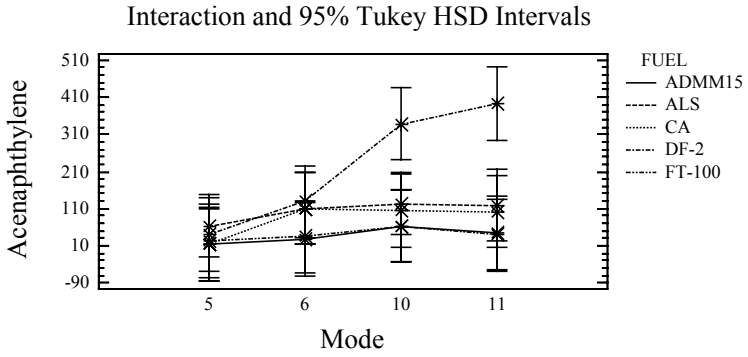
Multiple Range Tests for GACENAPH by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups

ADMM15	12	36.3934	X
FT-100	12	40.0148	X
CA	12	82.8226	X
ALS	14	104.521	X
DF-2	12	225.265	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-68.1281	70.9974
ADMM15 - CA	-46.4292	73.6775
ADMM15 - DF-2	*-188.872	73.6775
ADMM15 - FT-100	-3.62141	73.6775
ALS - CA	21.6988	70.9974
ALS - DF-2	*-120.744	70.9974
ALS - FT-100	64.5067	70.9974
CA - DF-2	*-142.443	73.6775
CA - FT-100	42.8078	73.6775
DF-2 - FT-100	*185.25	73.6775

* denotes a statistically significant difference.
Multifactor ANOVA - GACENAPH (MODE<12)



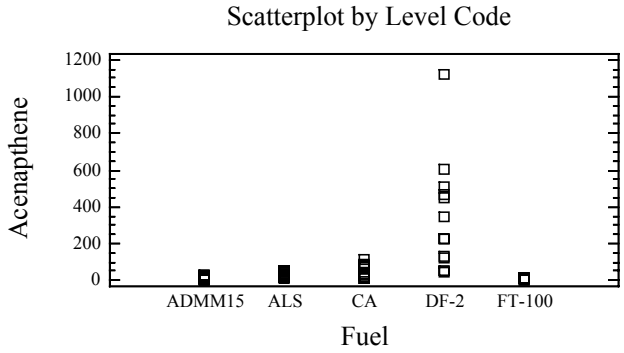
CONCLUSION: Modes 10 and 11 have significantly different average acenaphthylene for the DF-2 fuel. All other fuels do not demonstrate differences in the average acenaphthylene among the four modes.

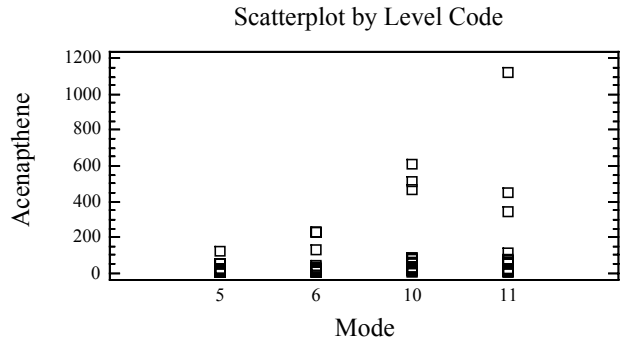
Multifactor ANOVA - Acenaphthene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: ACENAPTH
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



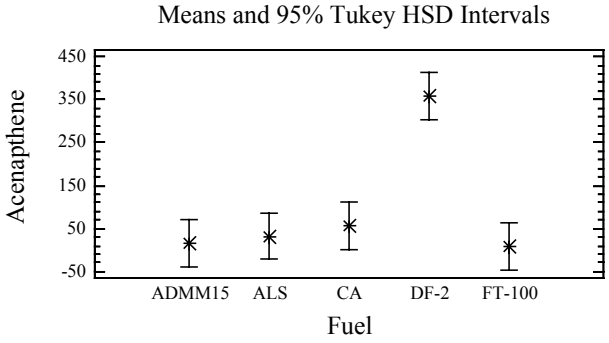


Analysis of Variance for ACENAPTH - Type III Sums of Squares

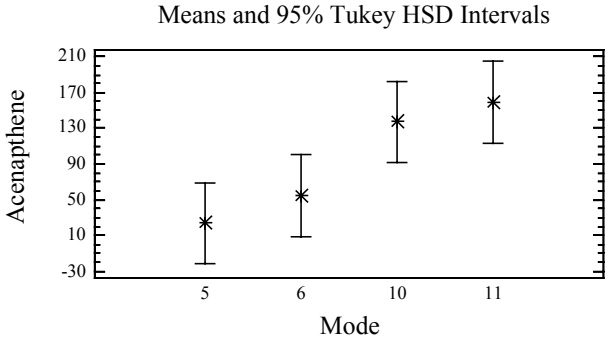
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1.07169E6	4	267923.0	29.63	0.0000
B:MODE	192968.0	3	64322.8	7.11	0.0006
INTERACTIONS					
AB	471924.0	12	39327.0	4.35	0.0002
RESIDUAL	379788.0	42	9042.56		
TOTAL (CORRECTED)	2.10838E6	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average acenaphthene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average acenaphthene for the DF-2 fuel is significantly different than the average acenaphthene for the remaining four fuels.



CONCLUSION: The average acenaphthene for mode 5 is significantly different than the average acenaphthene for modes 10 and 11. The average acenaphthene for mode 6 is significantly different than the average acenaphthene for mode 11.

Multiple Range Tests for ACENAPTH by FUEL

Method: 95.0 percent Tukey HSD

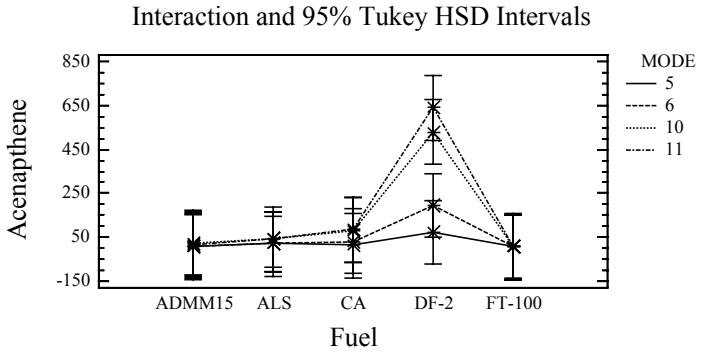
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	8.10026	X
ADMM15	12	15.5047	X
ALS	14	32.1103	X
CA	12	54.6557	X
DF-2	12	358.314	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-16.6056	106.617
ADMM15 - CA	-39.151	110.642
ADMM15 - DF-2	*-342.809	110.642
ADMM15 - FT-100	7.40444	110.642
ALS - CA	-22.5454	106.617
ALS - DF-2	*-326.204	106.617
ALS - FT-100	24.01	106.617
CA - DF-2	*-303.658	110.642
CA - FT-100	46.5554	110.642
DF-2 - FT-100	*350.214	110.642

* denotes a statistically significant difference.

Multiple Range Tests for ACENAPTH by MODE

```
------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE           Count     LS Mean           Homogeneous Groups
------------------------------------------------------------------------------
5              16        24.2191           X
6              15        54.4957           XX
10             16        137.565            XX
11             15        158.668             X
------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
------------------------------------------------------------------------------
5 - 6                                      -30.2766            91.4279
5 - 10                                    *-113.346            89.9412
5 - 11                                    *-134.449            91.4279
6 - 10                                     -83.0696            91.4279
6 - 11                                    *-104.172            92.8908
10 - 11                                    -21.1024            91.4279
------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



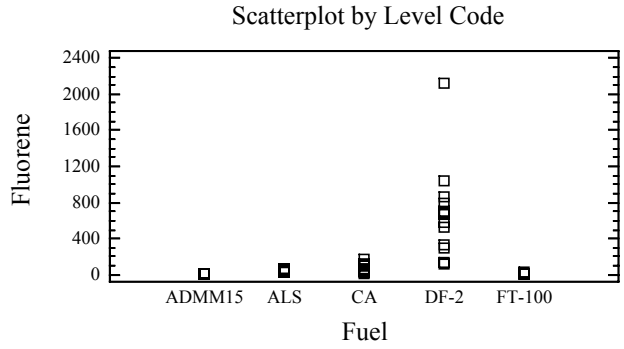
CONCLUSION: The average acenaphthene for the DF-2 fuel at modes 10 and 11 is is significantly different than the average acenaphthene for modes 5 and 6. All the other fuels do not demonstrate differences in the average acenaphthene among the four modes.

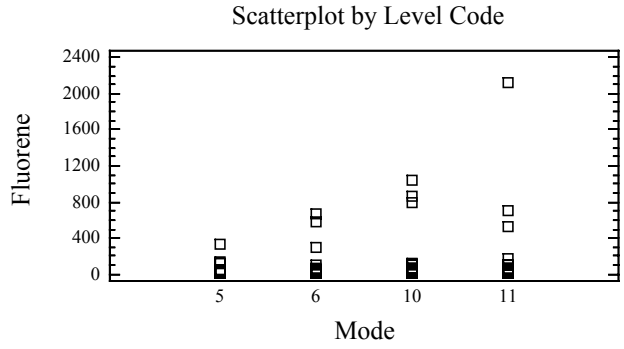
Multifactor ANOVA - Fluorene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: GFLUOREN
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



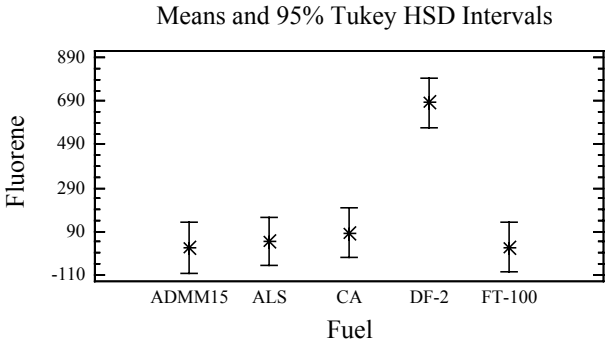


Analysis of Variance for GFLUOREN - Type III Sums of Squares

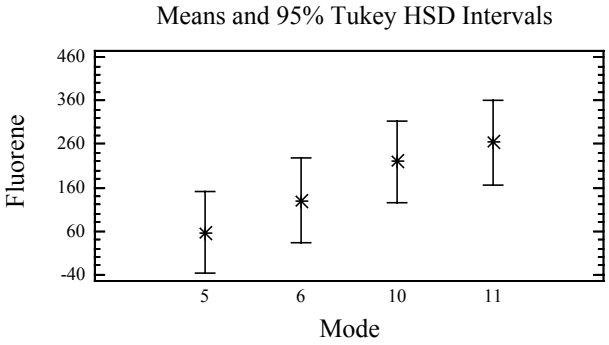
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	4.05735E6	4	1.01434E6	25.79	0.0000
B:MODE	399950.0	3	133317.0	3.39	0.0266
INTERACTIONS					
AB	1.14654E6	12	95545.3	2.43	0.0169
RESIDUAL	1.65166E6	42	39325.3		
TOTAL (CORRECTED)	7.23726E6	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average fluorene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average fluorene for the DF-2 fuel is significantly different than the average fluorene for the remaining four fuels.



CONCLUSION: The average fluorene for mode 5 is significantly different than the average fluorene for mode 11.

Multiple Range Tests for GFLUOREN by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	12	13.9645	X
FT-100	12	15.2342	X
ALS	14	42.389	X
CA	12	83.7276	X
DF-2	12	683.736	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-28.4245	222.34
ADMM15 - CA	-69.7631	230.733
ADMM15 - DF-2	*-669.772	230.733
ADMM15 - FT-100	-1.26976	230.733
ALS - CA	-41.3386	222.34
ALS - DF-2	*-641.347	222.34
ALS - FT-100	27.1547	222.34
CA - DF-2	*-600.009	230.733
CA - FT-100	68.4933	230.733
DF-2 - FT-100	*668.502	230.733

* denotes a statistically significant difference.

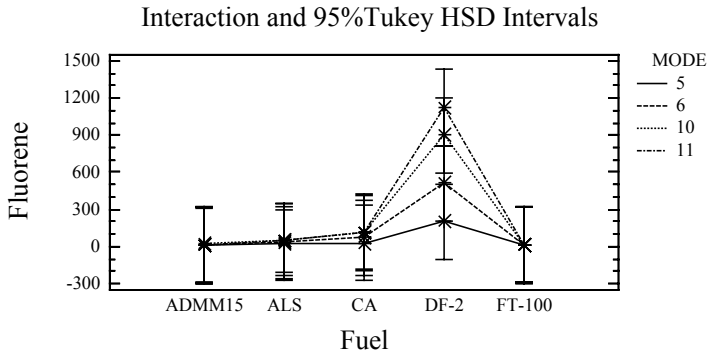
Multiple Range Tests for GFLUOREN by MODE

Method: 95.0 percent Tukey HSD

MODE	Count	LS Mean	Homogeneous Groups
5	16	56.4247	X
6	15	130.158	XX
10	16	220.709	XX
11	15	263.949	X

Contrast	Difference	+/- Limits
5 - 6	-73.7337	190.664
5 - 10	-164.284	187.564
5 - 11	*-207.525	190.664
6 - 10	-90.5503	190.664
6 - 11	-133.791	193.715
10 - 11	-43.2405	190.664

* denotes a statistically significant difference.



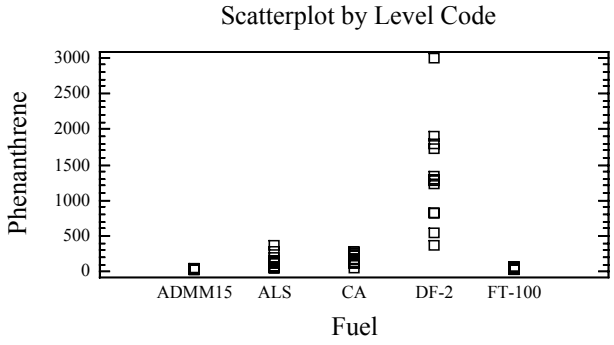
CONCLUSION: The average fluorene for the DF-2 fuel at modes 10 and 11 are significantly different than the average fluorene at mode 5. All the other fuels do not demonstrate differences in the average fluorene among the four modes.

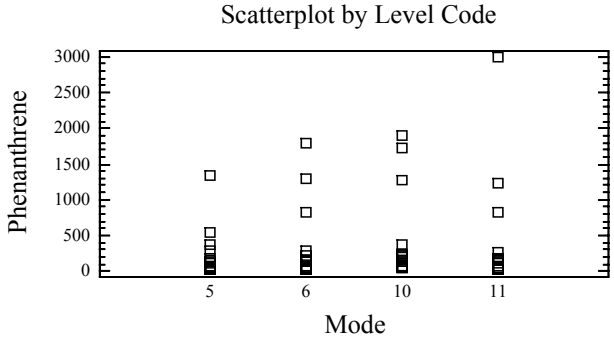
Multifactor ANOVA - Phenanthrene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: GPHENANT
Factors:
MODE
FUEL
Selection variable: MODE<12

Number of complete cases: 62



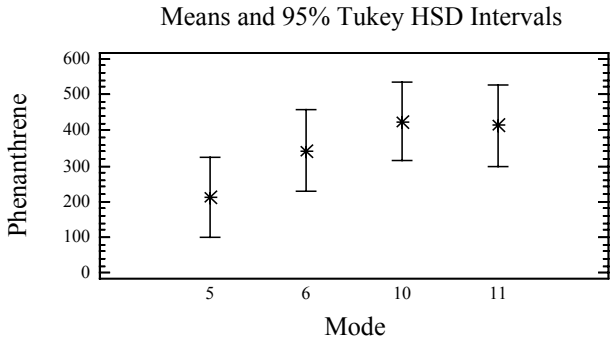


Analysis of Variance for GPHENANT - Type III Sums of Squares

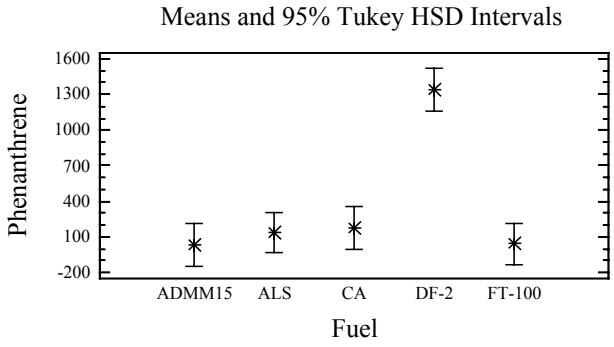
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MODE	448855.0	3	149618.0	1.58	0.2096
B:FUEL	1.51272E7	4	3.78179E6	39.81	0.0000
INTERACTIONS					
AB	1.2989E6	12	108242.0	1.14	0.3562
RESIDUAL	3.98957E6	42	94989.8		
TOTAL (CORRECTED)	2.08233E7	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average phenanthrene among the fuels.



CONCLUSION: No significant differences in the average phenanthrene among the four modes.



CONCLUSION: The average phenanthrene for the DF-2 fuel is significantly different than the other four fuels. The average phenanthrene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for GPHENANT by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
5	16	211.458	X
6	15	342.612	X
11	15	412.734	X
10	16	424.024	X

Contrast	Difference	+/- Limits
5 - 6	-131.154	296.327
5 - 10	-212.566	291.509
5 - 11	-201.276	296.327
6 - 10	-81.4119	296.327
6 - 11	-70.1218	301.069
10 - 11	11.29	296.327

* denotes a statistically significant difference.

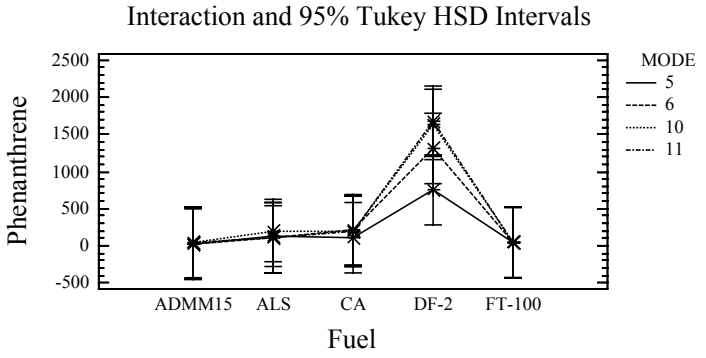
Multiple Range Tests for GPHENANT by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups

ADMM15	12	33.4535	X
FT-100	12	42.2233	X
ALS	14	139.715	X
CA	12	179.898	X
DF-2	12	1343.24	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-106.261	345.557
ADMM15 - CA	-146.445	358.601
ADMM15 - DF-2	*-1309.79	358.601
ADMM15 - FT-100	-8.76979	358.601
ALS - CA	-40.1836	345.557
ALS - DF-2	*-1203.53	345.557
ALS - FT-100	97.4916	345.557
CA - DF-2	*-1163.35	358.601
CA - FT-100	137.675	358.601
DF-2 - FT-100	*1301.02	358.601

* denotes a statistically significant difference.



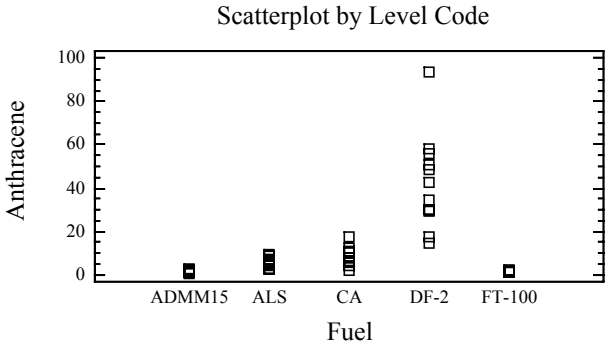
CONCLUSION: No significant differences among the fuel and mode combinations with respect to the average phenanthrene.

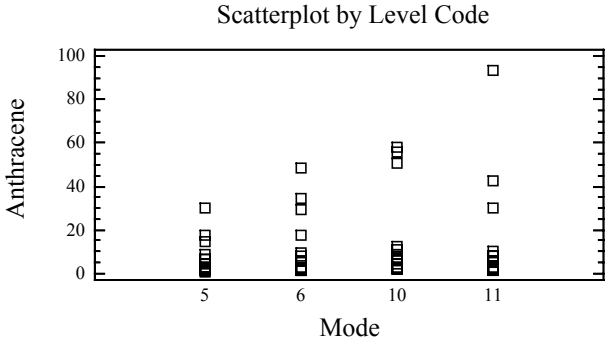
Multifactor ANOVA - Anthracene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: GANTHR
Factors:
MODE
FUEL
Selection variable: MODE<12

Number of complete cases: 62



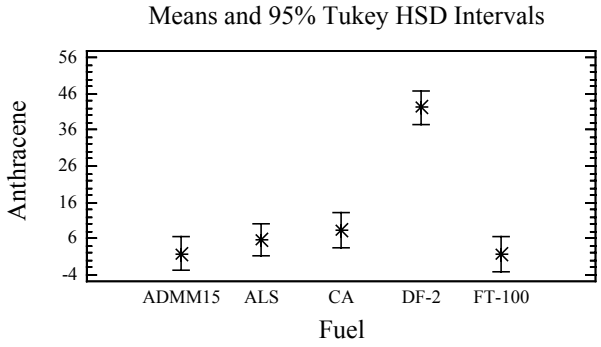


Analysis of Variance for GANTHR - Type III Sums of Squares

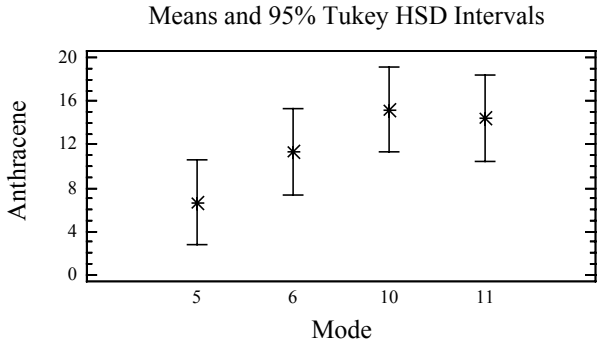
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MODE	709.29	3	236.43	3.54	0.0226
B:FUEL	14208.9	4	3552.23	53.11	0.0000
INTERACTIONS					
AB	1879.1	12	156.592	2.34	0.0210
RESIDUAL	2809.0	42	66.881		
TOTAL (CORRECTED)	19552.0	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average anthracene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average anthracene for the DF-2 fuel is significantly different than the other four fuels. The average anthracene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average anthracene for mode 5 is significantly different than the average anthracene for mode 10.

Multiple Range Tests for GANTHR by FUEL

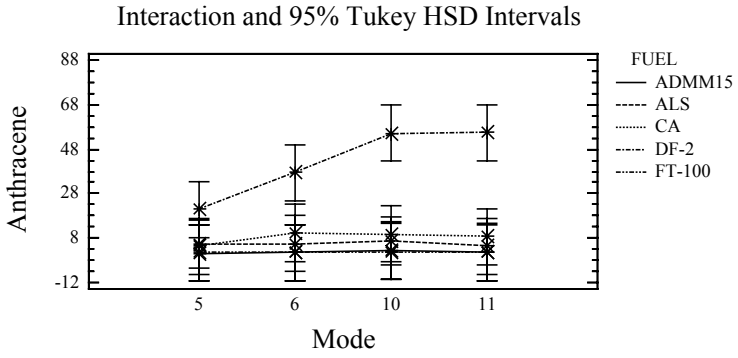
Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	1.64574	X
ADMM15	12	1.77037	X
ALS	14	5.54145	X
CA	12	8.30015	X
DF-2	12	42.1875	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-3.77108	9.16922
ADMM15 - CA	-6.52978	9.51535
ADMM15 - DF-2	*-40.4171	9.51535
ADMM15 - FT-100	0.124628	9.51535
ALS - CA	-2.7587	9.16922
ALS - DF-2	*-36.6461	9.16922
ALS - FT-100	3.89571	9.16922
CA - DF-2	*-33.8874	9.51535
CA - FT-100	6.6544	9.51535
DF-2 - FT-100	*40.5418	9.51535

* denotes a statistically significant difference.

Multiple Range Tests for GANTHR by MODE

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
5              16        6.63453           X
6              15        11.311            XX
11             15        14.414            XX
10             16        15.1967            X
-------------------------------------------------------------------------------
Contrast                                 Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                    -4.67649             7.86293
5 - 10                                  *-8.56213             7.73507
5 - 11                                   -7.77945             7.86293
6 - 10                                   -3.88563             7.86293
6 - 11                                   -3.10296             7.98875
10 - 11                                  0.782677             7.86293
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



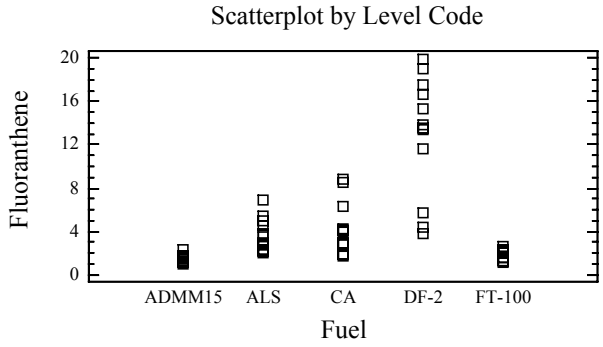
CONCLUSION: The average anthracene for the DF-2 fuel at modes 6, 10, and 11 are significantly different than the anthracene for the other four fuels.

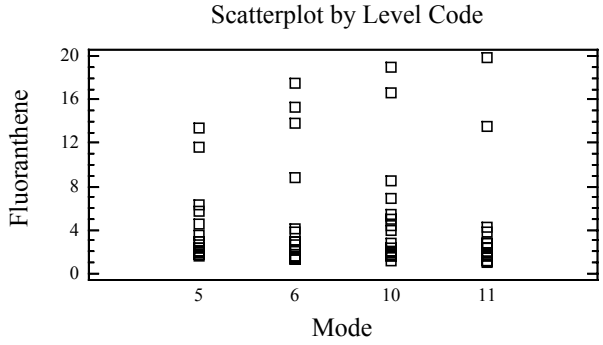
Multifactor ANOVA - Fluoranthene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: GFLUORAN
Factors:
FUEL
MODE
Selection variable: MODE<12

Number of complete cases: 62



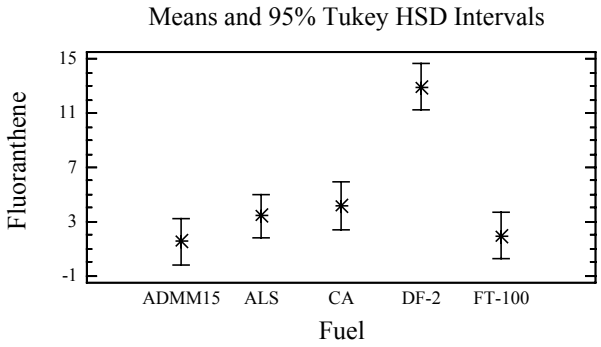


Analysis of Variance for GFLUORAN - Type III Sums of Squares

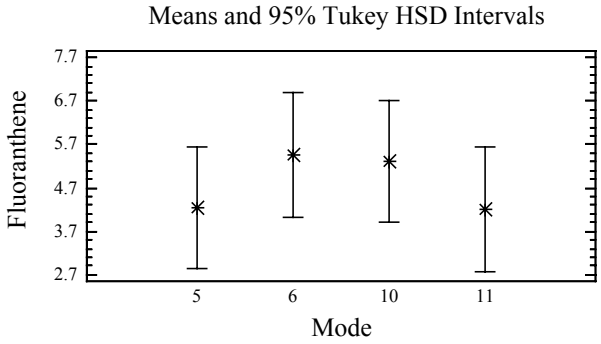
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1043.04	4	260.761	29.88	0.0000
B:MODE	21.1821	3	7.06069	0.81	0.4960
INTERACTIONS					
AB	46.5359	12	3.87799	0.44	0.9350
RESIDUAL	366.514	42	8.72654		
TOTAL (CORRECTED)	1474.87	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant difference in the average fluoranthene among the fuels.



CONCLUSION: The average fluoranthene for the DF-2 fuel is significantly different than the average fluoranthene for the remaining four fuels.



CONCLUSION: No significant differences in the average fluoranthene among the four modes.

Multiple Range Tests for GFLUORAN by FUEL

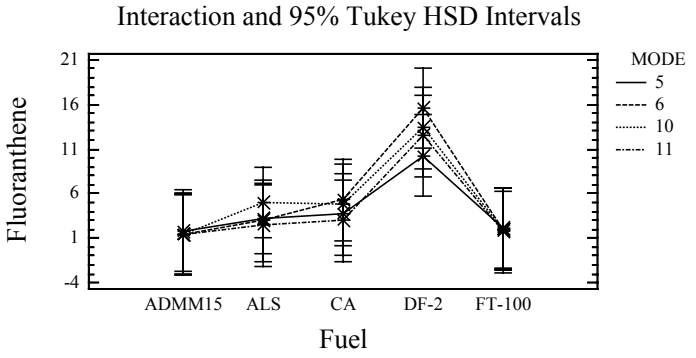
Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	12	1.55023	X
FT-100	12	1.97221	X
ALS	14	3.42001	X
CA	12	4.17341	X
DF-2	12	12.9117	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.86978	3.31209
ADMM15 - CA	-2.62318	3.43712
ADMM15 - DF-2	*-11.3614	3.43712
ADMM15 - FT-100	-0.421982	3.43712
ALS - CA	-0.753401	3.31209
ALS - DF-2	*-9.49167	3.31209
ALS - FT-100	1.4478	3.31209
CA - DF-2	*-8.73827	3.43712
CA - FT-100	2.2012	3.43712
DF-2 - FT-100	*10.9395	3.43712

* denotes a statistically significant difference.

Multiple Range Tests for GFLUORAN by MODE

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
11             15        4.20058           X
5              16        4.2397            X
10             16        5.32028           X
6              15        5.46146           X
-------------------------------------------------------------------------------
Contrast                                   Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                      -1.22176             2.84023
5 - 10                                     -1.08058             2.79405
5 - 11                                     0.0391235            2.84023
6 - 10                                     0.14118              2.84023
6 - 11                                     1.26088              2.88568
10 - 11                                    1.1197               2.84023
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



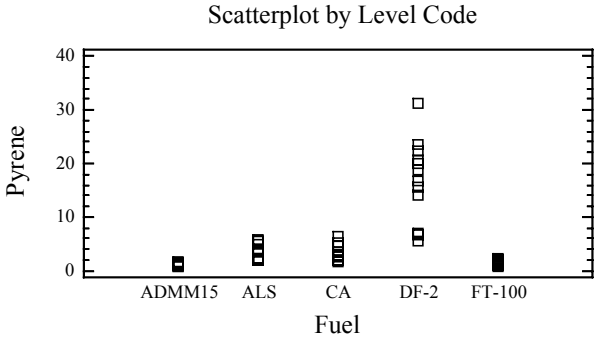
CONCLUSION: No significant differences among the fuel and mode combinations with respect to the average fluoranthene.

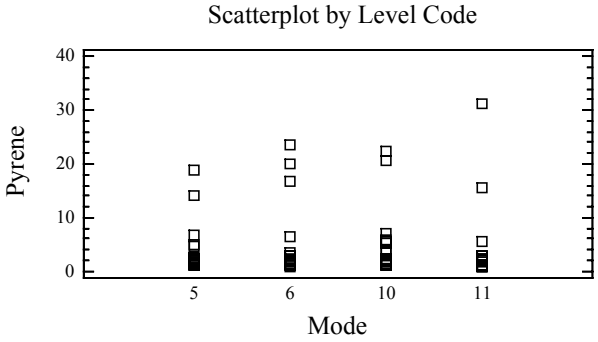
Multifactor ANOVA - Pyrene (µg/kW-hr) Gaseous PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: GPYRENE
Factors:
MODE
FUEL
Selection variable: MODE<12

Number of complete cases: 62



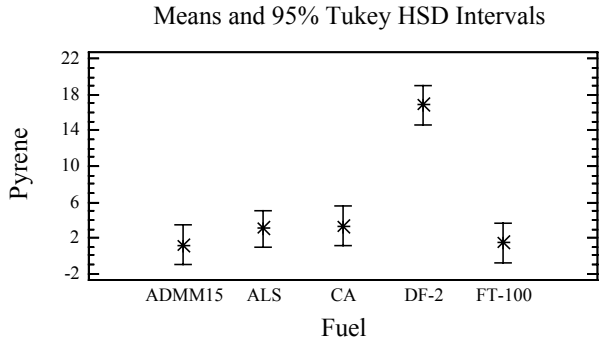


Analysis of Variance for GPYRENE - Type III Sums of Squares

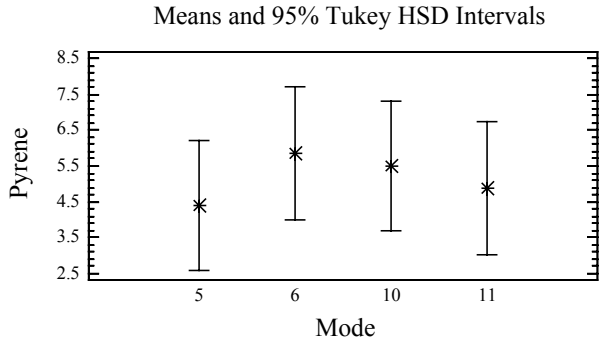
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MODE	19.8872	3	6.62908	0.46	0.7140
B:FUEL	2095.77	4	523.943	36.10	0.0000
INTERACTIONS					
AB	66.5375	12	5.54479	0.38	0.9628
RESIDUAL	609.636	42	14.5151		
TOTAL (CORRECTED)	2787.64	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average pyrene among the fuels.



CONCLUSION: The average pyrene for the DF-2 fuel is significantly different than the average pyrene for the remaining four fuels.



CONCLUSION: No significant differences in the average pyrene among the modes.

Multiple Range Tests for GPYRENE by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	12	1.17274	X
FT-100	12	1.46172	X
ALS	14	3.00746	X
CA	12	3.32296	X
DF-2	12	16.8399	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.83472	4.27161
ADMM15 - CA	-2.15021	4.43286
ADMM15 - DF-2	*-15.6672	4.43286
ADMM15 - FT-100	-0.288977	4.43286
ALS - CA	-0.315494	4.27161
ALS - DF-2	*-13.8324	4.27161
ALS - FT-100	1.54574	4.27161
CA - DF-2	*-13.5169	4.43286
CA - FT-100	1.86124	4.43286
DF-2 - FT-100	*15.3782	4.43286

* denotes a statistically significant difference.

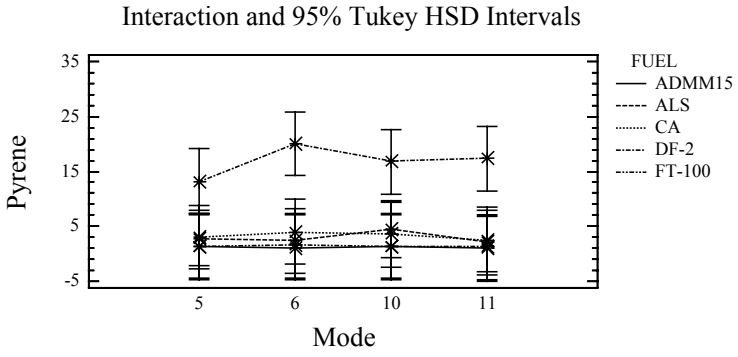
Multiple Range Tests for GPYRENE by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups

5	16	4.38002	X
11	15	4.89347	X
10	16	5.51762	X
6	15	5.85271	X

Contrast	Difference	+/- Limits
5 - 6	-1.47269	3.66306
5 - 10	-1.1376	3.60349
5 - 11	-0.513451	3.66306
6 - 10	0.335096	3.66306
6 - 11	0.959242	3.72167
10 - 11	0.624146	3.66306

* denotes a statistically significant difference.



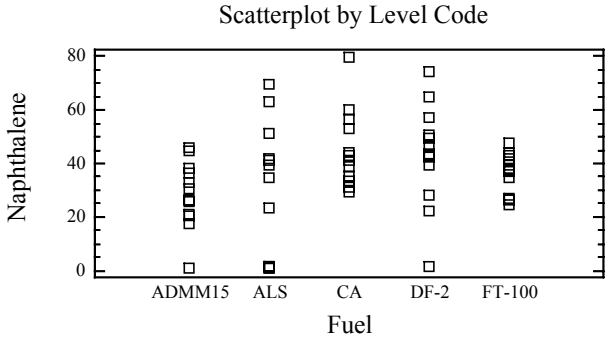
CONCLUSION: No significant differences among the fuel and mode combinations with respect to the average pyrene.

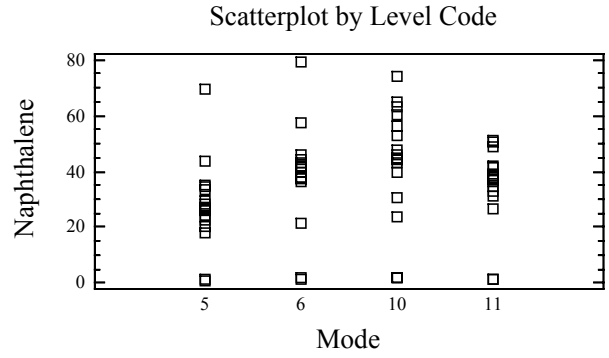
Multifactor ANOVA - Naphthalene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: naphth
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 62



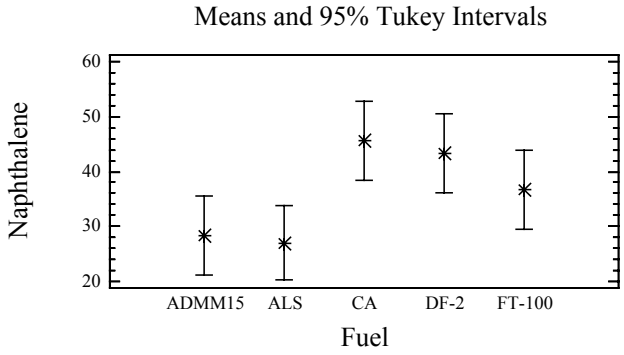


Analysis of Variance for naphth - Type III Sums of Squares

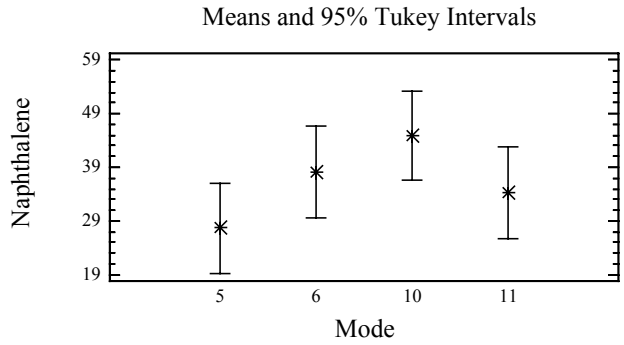
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	3529.36	4	882.34	2.92	0.0323
B:mode	2429.66	3	809.885	2.68	0.0592
INTERACTIONS					
AB	2205.48	12	183.79	0.61	0.8231
RESIDUAL	12698.1	42	302.335		
TOTAL (CORRECTED)	20659.1	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average naphthalene among the fuels and the modes.



CONCLUSION: The average naphthalene for the CA and DF-2 fuels are significantly different from the ADMM15 and ALS fuels, but not significantly different from one another. The average naphthalene for the ADMM15 and ALS fuels are not significantly different from one another.



CONCLUSION: The average naphthalene for mode 10 is significantly different from mode 5.

Multiple Range Tests for naphth by fuel

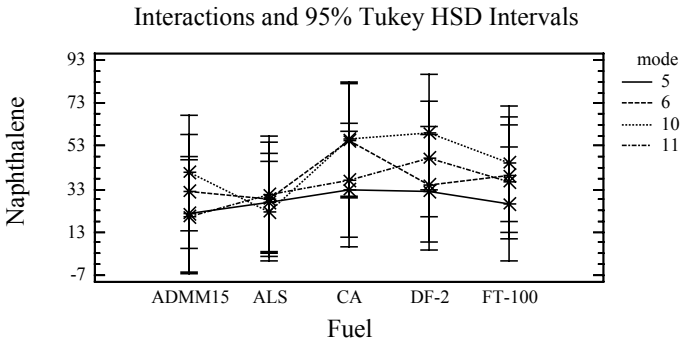
Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ALS	14	27.0444	X
ADMM15	12	28.4129	X
FT-100	12	36.7585	XX
DF-2	12	43.3494	X
CA	12	45.5031	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	1.36846	13.8043
ADMM15 - CA	*-17.0902	14.3254
ADMM15 - DF-2	*-14.9365	14.3254
ADMM15 - FT-100	-8.34559	14.3254
ALS - CA	*-18.4587	13.8043
ALS - DF-2	*-16.305	13.8043
ALS - FT-100	-9.71405	13.8043
CA - DF-2	2.15369	14.3254
CA - FT-100	8.74463	14.3254
DF-2 - FT-100	6.59093	14.3254

* denotes a statistically significant difference.

Multiple Range Tests for naphth by mode

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
mode           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
5              16        27.6477           X
11             15        34.3223           XX
6              15        38.0808           XX
10             16        44.8038            X
-------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                      -10.4332            16.7177
5 - 10                                    *-17.1562            16.4459
5 - 11                                     -6.67461            16.7177
6 - 10                                     -6.72301            16.7177
6 - 11                                     3.75857             16.9852
10 - 11                                    10.4816             16.7177
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



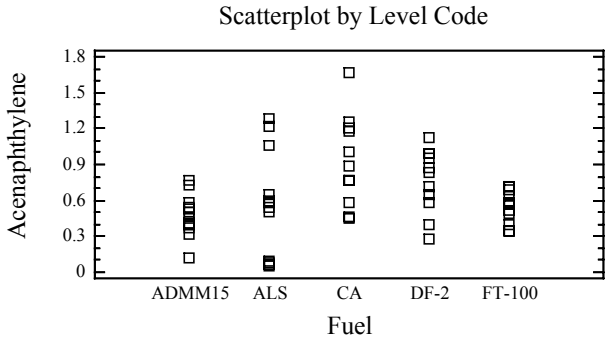
CONCLUSION: There is no significant interaction in the average naphthalene among the fuel and mode combinations.

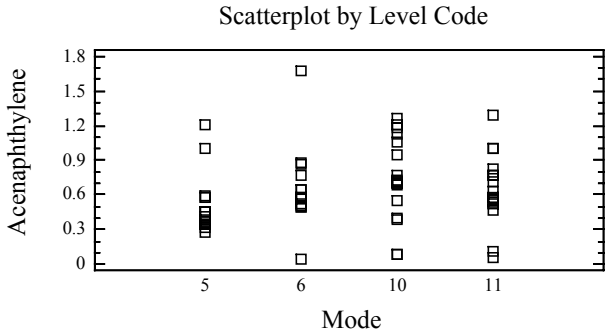
Multifactor ANOVA - Acenaphthylene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: acenaph
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 59



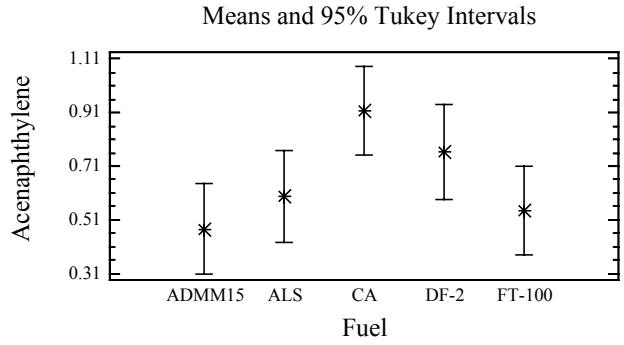


Analysis of Variance for acenaph - Type III Sums of Squares

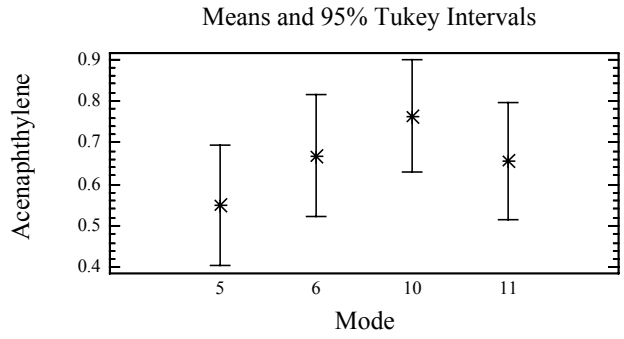
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1.49999	4	0.374998	4.66	0.0036
B:mode	0.335426	3	0.111809	1.39	0.2600
INTERACTIONS					
AB	1.32025	12	0.110021	1.37	0.2221
RESIDUAL	3.13513	39	0.0803879		
TOTAL (CORRECTED)	6.44463	58			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average acenaphthylene among the fuels.



CONCLUSION: The average acenaphthylene for the CA fuel is significantly different than the FT-100 and ADMM15 fuels.



CONCLUSION: No statistically significant differences in the average acenaphthylene among the modes.

Multiple Range Tests for acenaph by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	12	0.476752	X
FT-100	12	0.544934	X
ALS	12	0.597067	XX
DF-2	11	0.762226	XX
CA	12	0.915322	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.120315	0.331015
ADMM15 - CA	*-0.43857	0.331015
ADMM15 - DF-2	-0.285475	0.338455
ADMM15 - FT-100	-0.0681826	0.331015
ALS - CA	-0.318255	0.331015
ALS - DF-2	-0.16516	0.338455
ALS - FT-100	0.0521325	0.331015
CA - DF-2	0.153096	0.338455
CA - FT-100	*0.370388	0.331015
DF-2 - FT-100	0.217292	0.338455

* denotes a statistically significant difference.

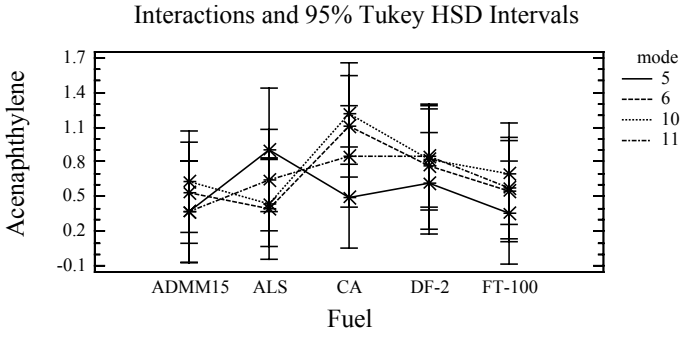
Multiple Range Tests for acenaph by mode

Method: 95.0 percent Tukey HSD

mode	Count	LS Mean	Homogeneous Groups
5	14	0.549292	X
11	15	0.65586	X
6	14	0.668896	X
10	16	0.762994	X

Contrast	Difference	+/- Limits
5 - 6	-0.119604	0.28759
5 - 10	-0.213702	0.278458
5 - 11	-0.106568	0.282757
6 - 10	-0.0940977	0.278458
6 - 11	0.0130359	0.282757
10 - 11	0.107134	0.273463

* denotes a statistically significant difference.



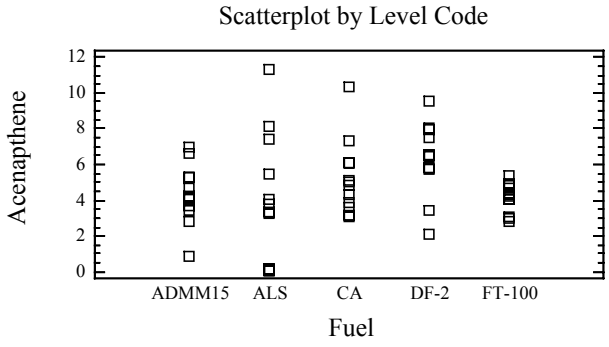
CONCLUSION: There is no significant interaction in the average acenaphthylene among the fuel and mode combinations.

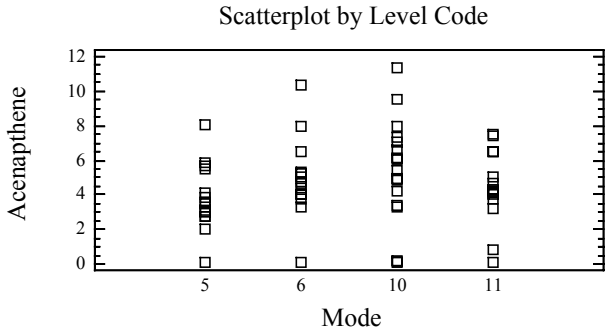
Multifactor ANOVA - Acenaphthene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: acenapth
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 60



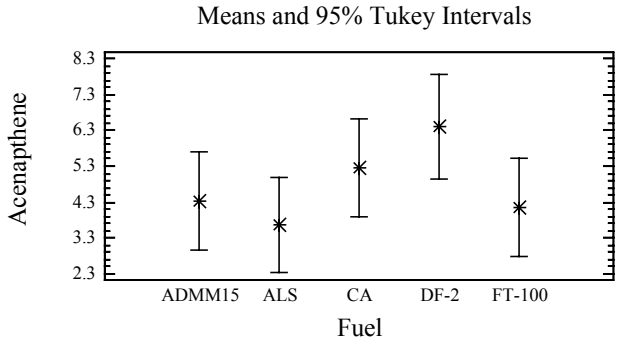


Analysis of Variance for acenapth - Type III Sums of Squares

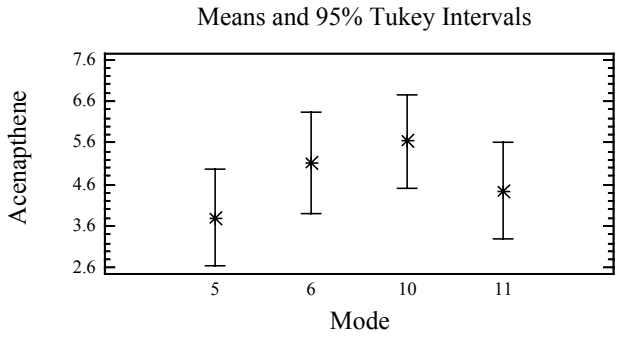
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	53.5982	4	13.3995	2.42	0.0646
B:mode	29.3303	3	9.77675	1.76	0.1699
INTERACTIONS					
AB	37.0561	12	3.088	0.56	0.8629
RESIDUAL	221.911	40	5.54777		
TOTAL (CORRECTED)	338.487	59			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average acenaphthene among the fuels, modes or interaction.



CONCLUSION: No statistically significant differences in the average acenaphthene among the fuels.



CONCLUSION: No statistically significant differences in the average acenaphthene among the modes.

Multiple Range Tests for acenapth by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ALS	13	3.64246	X
FT-100	12	4.14432	X
ADMM15	12	4.34272	X
CA	12	5.23877	X
DF-2	11	6.3927	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	0.700254	2.69325
ADMM15 - CA	-0.896057	2.74659
ADMM15 - DF-2	-2.04998	2.80832
ADMM15 - FT-100	0.198397	2.74659
ALS - CA	-1.59631	2.69325
ALS - DF-2	-2.75023	2.75618
ALS - FT-100	-0.501857	2.69325
CA - DF-2	-1.15392	2.80832
CA - FT-100	1.09445	2.74659
DF-2 - FT-100	2.24838	2.80832

* denotes a statistically significant difference.

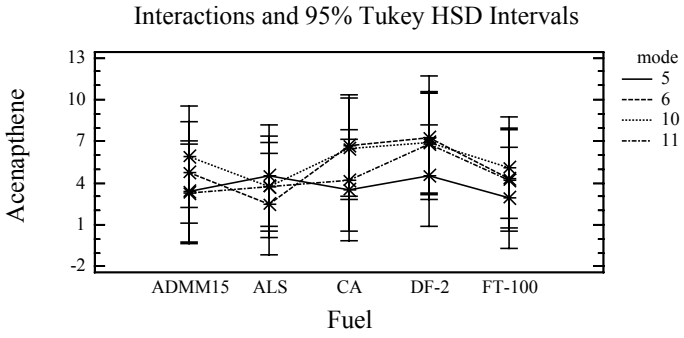
Multiple Range Tests for acenapth by mode

Method: 95.0 percent Tukey HSD

mode	Count	LS Mean	Homogeneous Groups
5	15	3.80127	X
11	15	4.44134	X
6	14	5.12813	X
10	16	5.63804	X

Contrast	Difference	+/- Limits
5 - 6	-1.32686	2.34637
5 - 10	-1.83677	2.26925
5 - 11	-0.640065	2.30556
6 - 10	-0.509911	2.3107
6 - 11	0.686793	2.34637
10 - 11	1.1967	2.26925

* denotes a statistically significant difference.



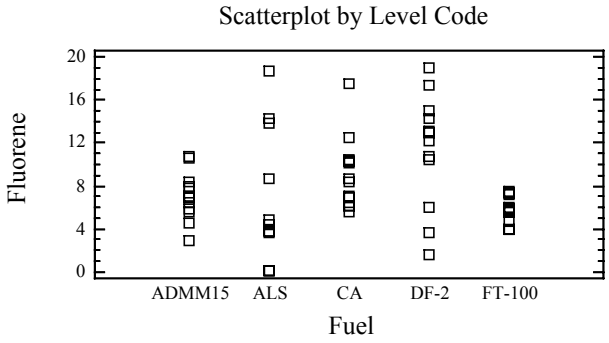
CONCLUSION: There is no significant interaction in the average acenaphthene among the fuel and mode combinations.

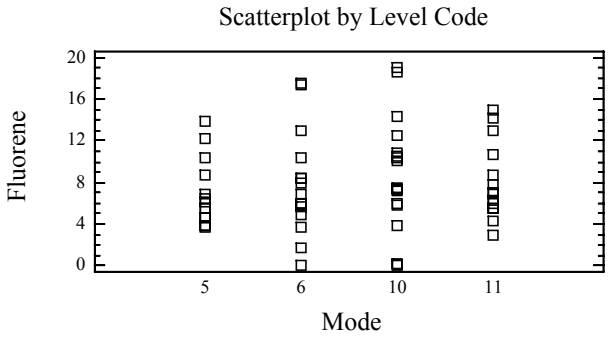
Multifactor ANOVA - Fluorene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: fluorene
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 59



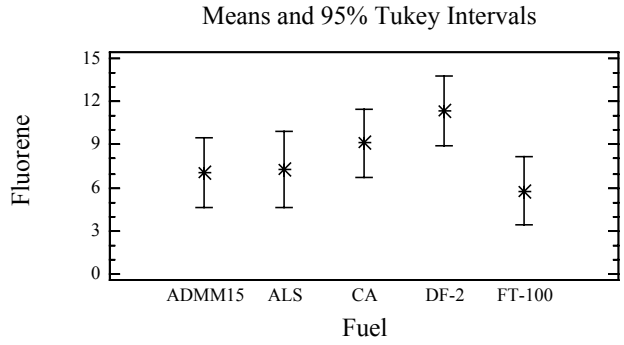


Analysis of Variance for fluorene - Type III Sums of Squares

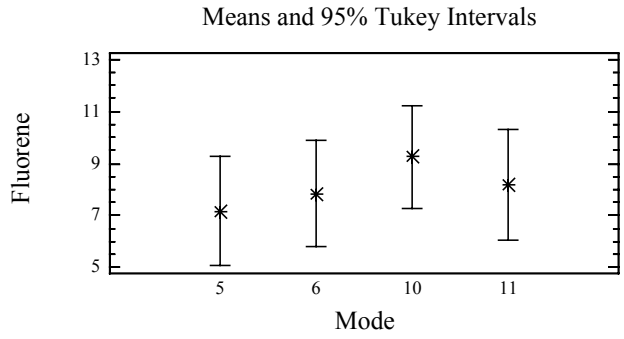
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	224.986	4	56.2465	3.31	0.0198
B:mode	33.6482	3	11.2161	0.66	0.5811
INTERACTIONS					
AB	212.384	12	17.6986	1.04	0.4317
RESIDUAL	661.915	39	16.9722		
TOTAL (CORRECTED)	1158.59	58			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average fluorene among the fuels.



CONCLUSION: The average fluorene for the DF-2 fuel is significantly different from the FT-100 fuel.



CONCLUSION: There is no significant difference in the average fluorene among the modes.

Multiple Range Tests for fluorene by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
FT-100	12	5.76877	X
ADMM15	12	7.04309	XX
ALS	11	7.27518	XX
CA	12	9.12758	XX
DF-2	12	11.3521	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.232095	4.91784
ADMM15 - CA	-2.08449	4.80974
ADMM15 - DF-2	-4.30904	4.80974
ADMM15 - FT-100	1.27432	4.80974
ALS - CA	-1.8524	4.91784
ALS - DF-2	-4.07695	4.91784
ALS - FT-100	1.50641	4.91784
CA - DF-2	-2.22455	4.80974
CA - FT-100	3.35881	4.80974
DF-2 - FT-100	*5.58336	4.80974

* denotes a statistically significant difference.

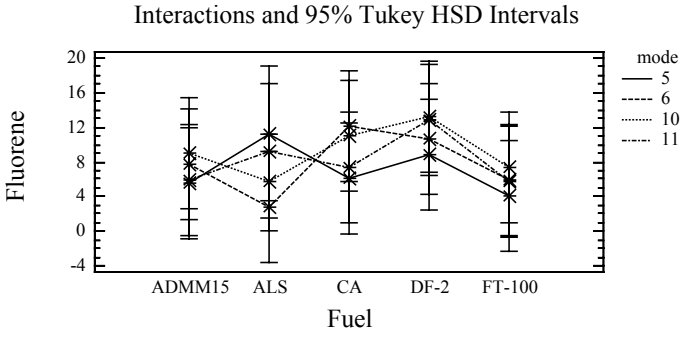
Multiple Range Tests for fluorene by mode

Method: 95.0 percent Tukey HSD

mode	Count	LS Mean	Homogeneous Groups
5	14	7.17223	X
6	15	7.83432	X
11	14	8.19741	X
10	16	9.24944	X

Contrast	Difference	+/- Limits
5 - 6	-0.662093	4.10853
5 - 10	-2.07721	4.04607
5 - 11	-1.02518	4.17876
6 - 10	-1.41512	3.97349
6 - 11	-0.363092	4.10853
10 - 11	1.05203	4.04607

* denotes a statistically significant difference.



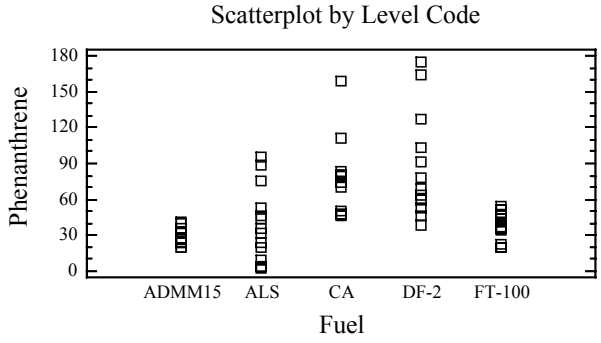
CONCLUSION: There is no significant interaction in the average fluorene among the fuel and mode combinations.

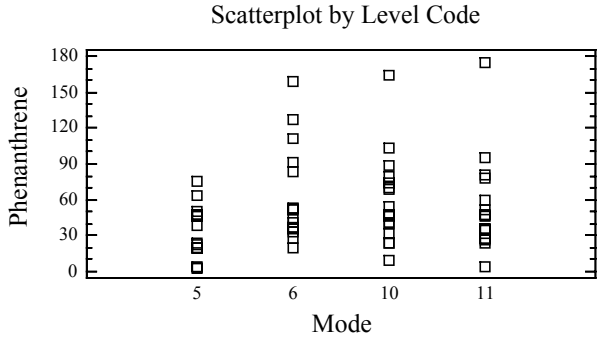
Multifactor ANOVA - Phenanthrene (µg/kW-hr) Soluble PAH
LPP Only modes 5,6,10,11

Analysis Summary

Dependent variable: phenanth
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 62



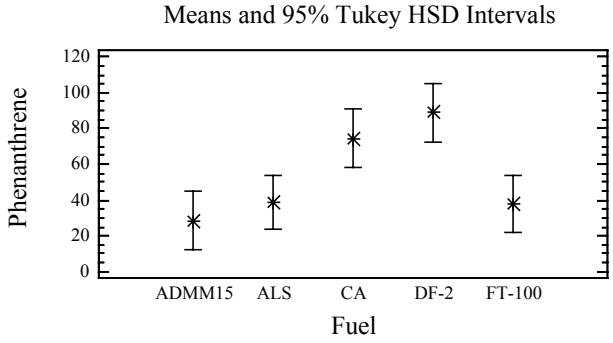


Analysis of Variance for phenanth - Type III Sums of Squares

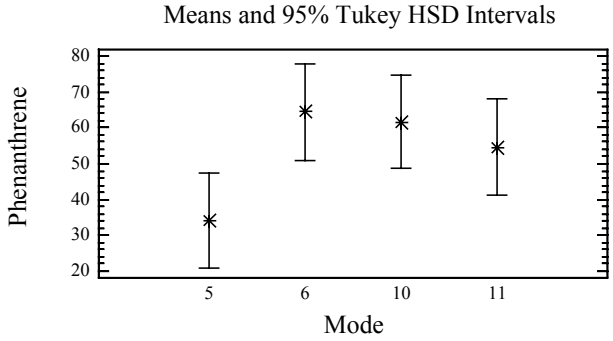
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	33757.8	4	8439.44	11.05	0.0000
B:mode	8830.11	3	2943.37	3.85	0.0159
INTERACTIONS					
AB	9241.53	12	770.128	1.01	0.4585
RESIDUAL	32075.1	42	763.693		
TOTAL (CORRECTED)	83646.1	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average phenanthrene among the fuels and modes.



CONCLUSION: There are two distinct fuel groupings with respect to the average phenanthrene. The average phenanthrene for the DF-2 and CA fuels are not significantly different from one another, but are significantly different from the remaining three fuels. The average phenanthrene for the ALS, FT-100, and ADMM15 fuels are not significantly different from one another.



CONCLUSION: The average phenanthrene for mode 5 is significantly different from modes 6 and 10.

Multiple Range Tests for phenanth by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	12	28.5429	X
FT-100	12	38.1595	X
ALS	14	38.3617	X
CA	12	74.605	X
DF-2	12	88.8256	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-9.8188	30.9842
ADMM15 - CA	*-46.0621	32.1538
ADMM15 - DF-2	*-60.2827	32.1538
ADMM15 - FT-100	-9.61664	32.1538
ALS - CA	*-36.2433	30.9842
ALS - DF-2	*-50.4639	30.9842
ALS - FT-100	0.202164	30.9842
CA - DF-2	-14.2206	32.1538
CA - FT-100	*36.4455	32.1538
DF-2 - FT-100	*50.6661	32.1538

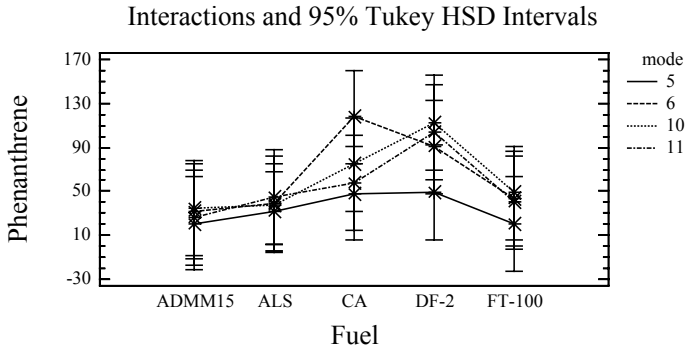
* denotes a statistically significant difference.

Multiple Range Tests for phenanth by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups
5	16	34.0794	X
11	15	54.571	XX
10	16	61.7122	X
6	15	64.4332	X

Contrast	Difference	+/- Limits
5 - 6	*-30.3539	26.57
5 - 10	*-27.6329	26.138
5 - 11	-20.4916	26.57
6 - 10	2.72099	26.57
6 - 11	9.86225	26.9952
10 - 11	7.14126	26.57

* denotes a statistically significant difference.



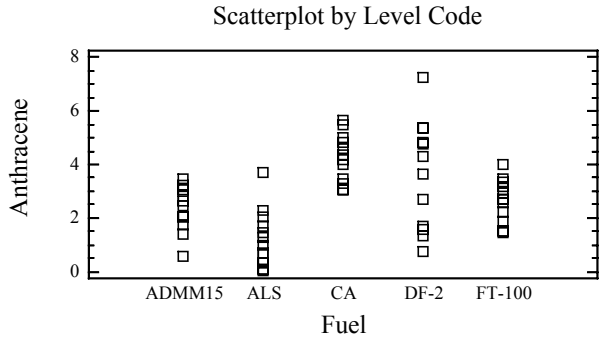
CONCLUSION: There is no significant interaction in the average phenanthrene among the fuel and mode combinations.

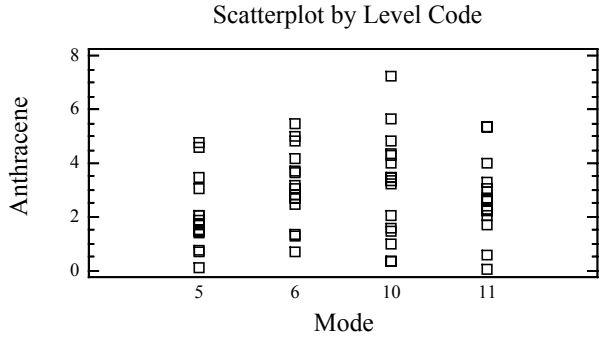
Multifactor ANOVA - Anthracene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: anthr
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 61



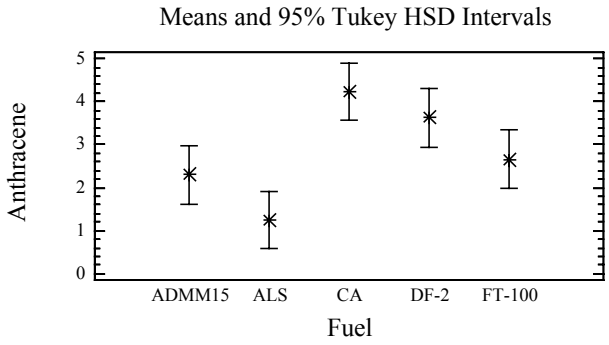


Analysis of Variance for anthr - Type III Sums of Squares

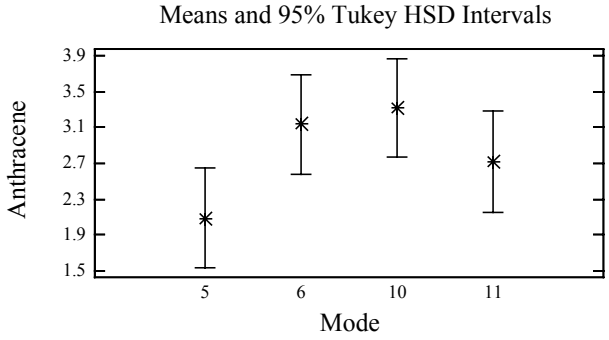
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	67.4897	4	16.8724	12.74	0.0000
B:mode	13.7647	3	4.58822	3.46	0.0248
INTERACTIONS					
AB	13.3777	12	1.11481	0.84	0.6090
RESIDUAL	54.3166	41	1.3248		
TOTAL (CORRECTED)	150.016	60			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average anthracene among the fuels and modes.



CONCLUSION: The average anthracene for the CA fuel is significantly different from the FT-100, ADMM15, and ALS fuels. The average anthracene for the ALS fuel is significantly different than the DF-2 and FT-100 fuels.



CONCLUSION: The average anthracene for mode 10 is significantly different than mode 5.

Multiple Range Tests for anthr by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ALS	13	1.2457	X
ADMM15	12	2.29932	XX
FT-100	12	2.66069	X
DF-2	12	3.62913	XX
CA	12	4.24561	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	1.05362	1.31462
ADMM15 - CA	*-1.94629	1.34065
ADMM15 - DF-2	-1.32981	1.34065
ADMM15 - FT-100	-0.361364	1.34065
ALS - CA	*-2.99991	1.31462
ALS - DF-2	*-2.38344	1.31462
ALS - FT-100	*-1.41499	1.31462
CA - DF-2	0.616475	1.34065
CA - FT-100	*1.58492	1.34065
DF-2 - FT-100	0.968447	1.34065

* denotes a statistically significant difference.

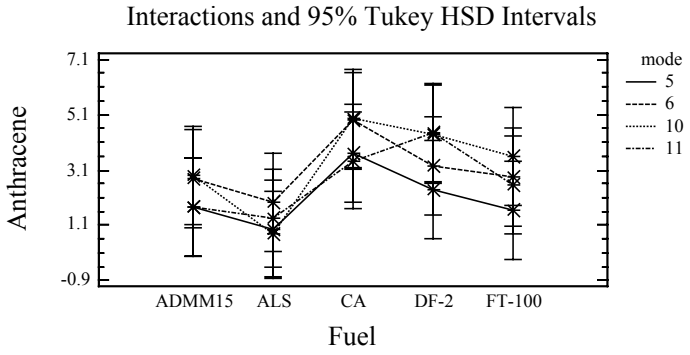
Multiple Range Tests for anthr by mode

Method: 95.0 percent Tukey HSD

mode	Count	LS Mean	Homogeneous Groups
5	15	2.08723	X
11	15	2.7156	XX
6	15	3.13382	XX
10	16	3.32771	X

Contrast	Difference	+/- Limits
5 - 6	-1.0466	1.12548
5 - 10	*-1.24048	1.10775
5 - 11	-0.628376	1.12548
6 - 10	-0.193884	1.10775
6 - 11	0.418221	1.12548
10 - 11	0.612105	1.10775

* denotes a statistically significant difference.



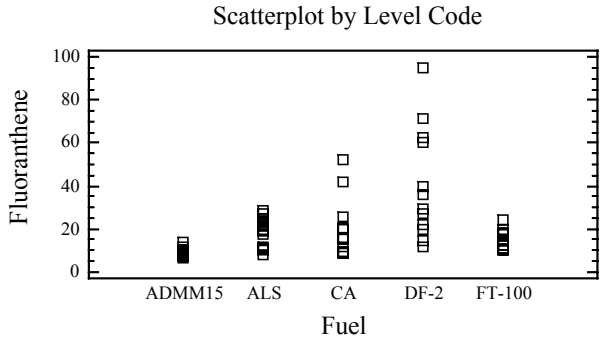
CONCLUSION: There is no significant interaction in the average anthracene among the fuel and mode combinations.

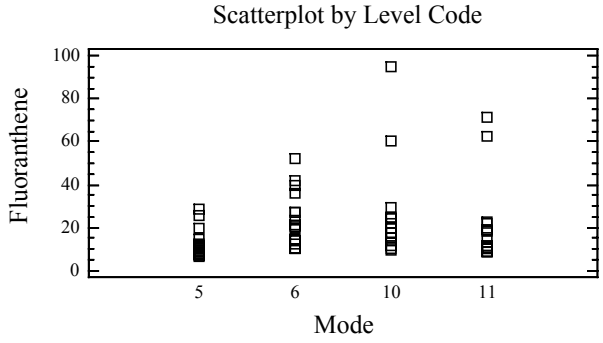
Multifactor ANOVA - Fluoranthene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: fluoran
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 62



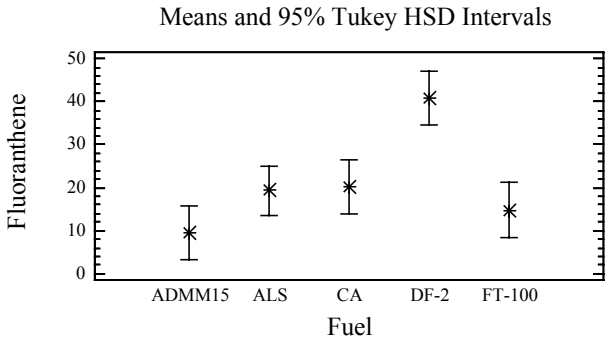


Analysis of Variance for fluoran - Type III Sums of Squares

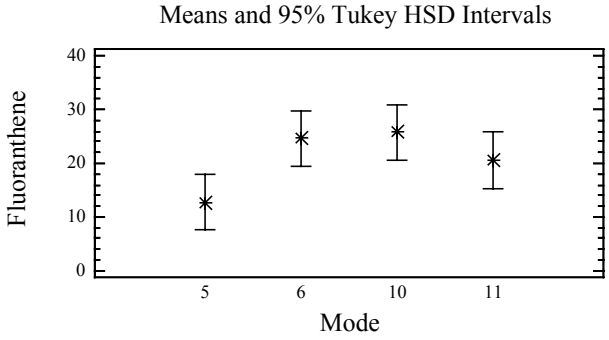
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	6792.8	4	1698.2	14.46	0.0000
B:mode	1674.88	3	558.292	4.75	0.0061
INTERACTIONS					
AB	3754.7	12	312.892	2.66	0.0094
RESIDUAL	4933.61	42	117.467		
TOTAL (CORRECTED)	17092.2	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average fluoranthene among the fuels, modes and fuel*mode interaction.



CONCLUSION: The average fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average fluoranthene for modes 6 and 10 are signficantly different than mode 5, but not significantly different from one another.

Multiple Range Tests for fluoran by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	12	9.4552	X
FT-100	12	14.8235	X
ALS	14	19.2862	X
CA	12	20.3461	X
DF-2	12	40.7715	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-9.83103	12.1517
ADMM15 - CA	-10.8909	12.6105
ADMM15 - DF-2	*-31.3163	12.6105
ADMM15 - FT-100	-5.36831	12.6105
ALS - CA	-1.0599	12.1517
ALS - DF-2	*-21.4853	12.1517
ALS - FT-100	4.46272	12.1517
CA - DF-2	*-20.4254	12.6105
CA - FT-100	5.52262	12.6105
DF-2 - FT-100	*25.948	12.6105

* denotes a statistically significant difference.

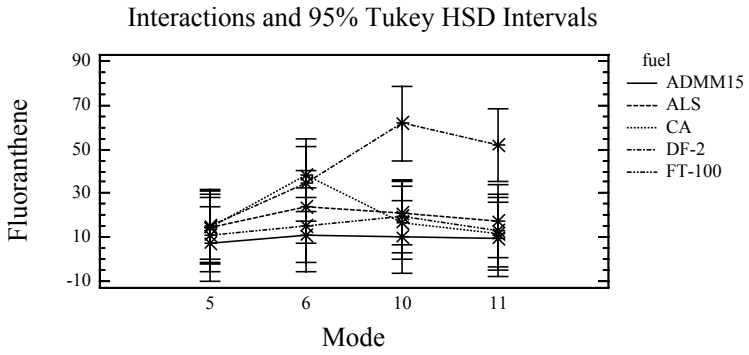
Multiple Range Tests for fluoran by mode

Method: 95.0 percent Tukey HSD

mode	Count	LS Mean	Homogeneous Groups
5	16	12.6339	X
11	15	20.6494	XX
6	15	24.5815	X
10	16	25.8812	X

Contrast	Difference	+/- Limits
5 - 6	*-11.9476	10.4206
5 - 10	*-13.2473	10.2511
5 - 11	-8.01553	10.4206
6 - 10	-1.29968	10.4206
6 - 11	3.93205	10.5873
10 - 11	5.23173	10.4206

* denotes a statistically significant difference.



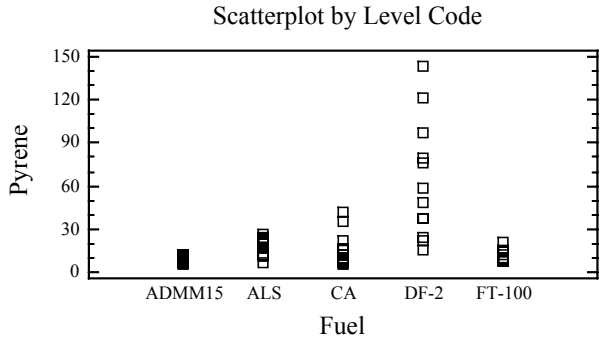
CONCLUSION: The trend in the average fluoranthene across the modes for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average fluoranthene for the DF-2 fuel at modes 10 and 11 are significantly different than the other four fuels.

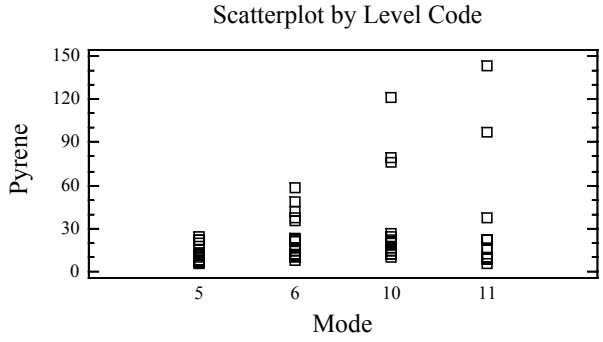
Multifactor ANOVA - Pyrene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: pyrene
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 62



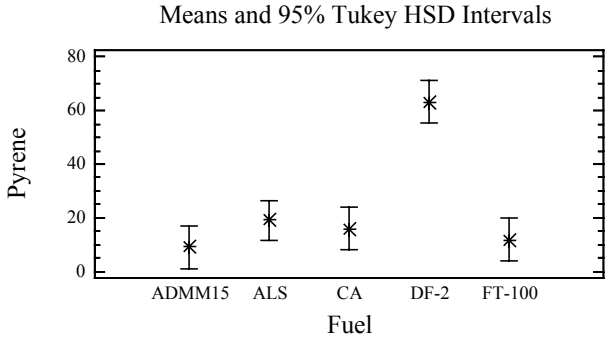


Analysis of Variance for pyrene - Type III Sums of Squares

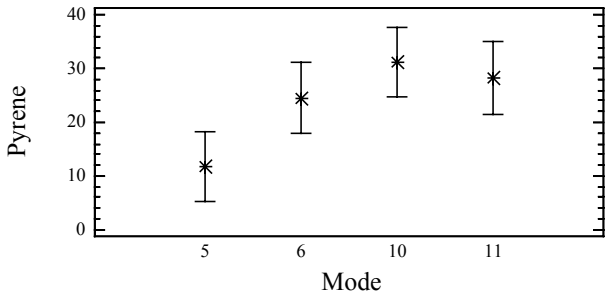
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	24058.4	4	6014.59	31.97	0.0000
B:mode	3466.4	3	1155.47	6.14	0.0015
INTERACTIONS					
AB	9336.65	12	778.054	4.14	0.0003
RESIDUAL	7901.13	42	188.122		
TOTAL (CORRECTED)	44659.6	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average pyrene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The average pyrene for the ASL, CA, FT-100, and ADMM15 fuels are not significantly different from one another.



CONCLUSION: The average pyrene for modes 10 and 11 are significantly different than mode 5. The average pyrene for mode 6 is not significantly different than the remaining three modes.

Multiple Range Tests for pyrene by fuel

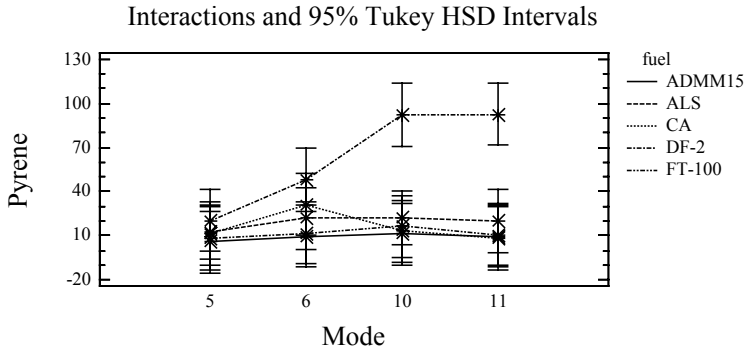
Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	12	9.0201	X
FT-100	12	11.872	X
CA	12	16.0453	X
ALS	14	19.177	X
DF-2	12	63.2917	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-10.1569	15.378
ADMM15 - CA	-7.02516	15.9585
ADMM15 - DF-2	*-54.2716	15.9585
ADMM15 - FT-100	-2.85191	15.9585
ALS - CA	3.13175	15.378
ALS - DF-2	*-44.1147	15.378
ALS - FT-100	7.30501	15.378
CA - DF-2	*-47.2464	15.9585
CA - FT-100	4.17325	15.9585
DF-2 - FT-100	*51.4197	15.9585

* denotes a statistically significant difference.

Multiple Range Tests for pyrene by mode

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
mode           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
5              16        11.6778           X
6              15        24.5073           XX
11             15        28.2235            X
10             16        31.1162            X
-------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                      -12.8295            13.1872
5 - 10                                    *-19.4385            12.9728
5 - 11                                    *-16.5458            13.1872
6 - 10                                     -6.60898            13.1872
6 - 11                                     -3.71629            13.3982
10 - 11                                    2.8927              13.1872
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



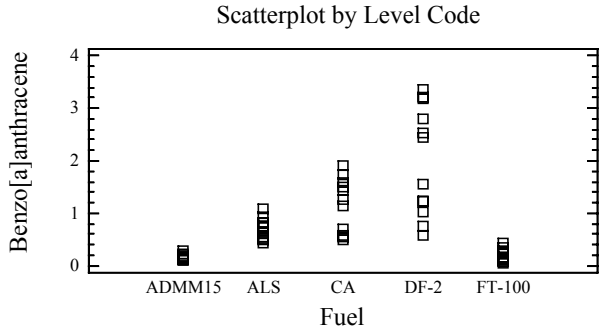
CONCLUSION: The trend in the average pyrene across the modes for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average pyrene at modes 10 and 11 for the DF-2 fuel are significantly different than the other four fuels.

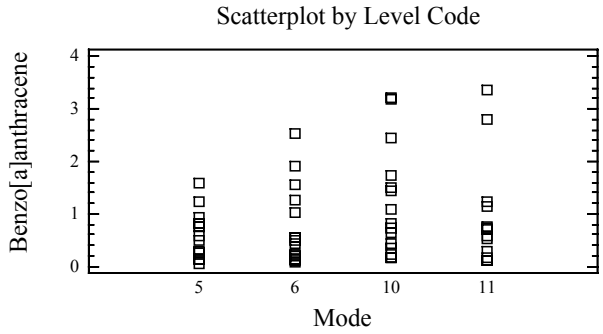
Multifactor ANOVA - Benzo[a]anthracene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: benzoaan
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 60



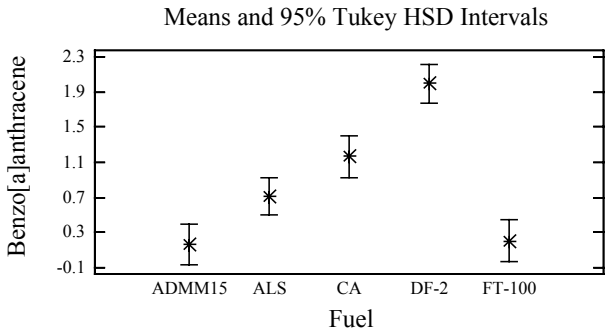


Analysis of Variance for benzoaan - Type III Sums of Squares

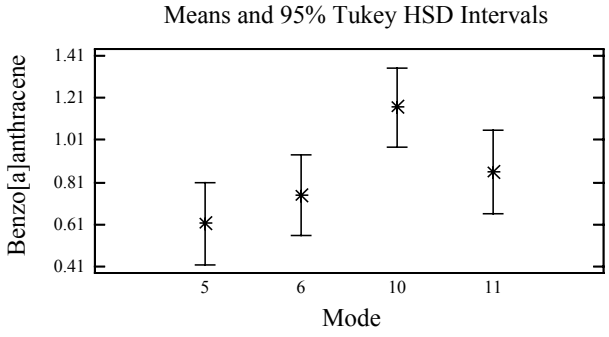
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	27.1788	4	6.79471	44.20	0.0000
B:mode	2.53806	3	0.84602	5.50	0.0029
INTERACTIONS					
AB	6.32452	12	0.527043	3.43	0.0016
RESIDUAL	6.14848	40	0.153712		
TOTAL (CORRECTED)	42.1988	59			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[a]anthracene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: There are four distinct fuel groupings with respect to the average benzo[a]anthracene. Fuels DF-2, CA, and ALS are significantly different from one another and the remaining two fuels. The FT-100 and ADMM15 fuels are not significantly different from one another, but are significantly different than the other three fuels.



CONCLUSION: The average benzo[a]anthracene for mode 10 is significantly different than modes 5 and 6. The average benzo[a]anthracene for mode 11 is not significantly different than the remaining three modes.

Multiple Range Tests for benzoaan by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	12	0.163625	X
FT-100	11	0.204025	X
ALS	14	0.70536	X
CA	11	1.16275	X
DF-2	12	1.99543	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.541735	0.440551
ADMM15 - CA	*-0.999128	0.467457
ADMM15 - DF-2	*-1.83181	0.457182
ADMM15 - FT-100	-0.0404	0.467457
ALS - CA	*-0.457393	0.451205
ALS - DF-2	*-1.29007	0.440551
ALS - FT-100	*0.501335	0.451205
CA - DF-2	*-0.832681	0.467457
CA - FT-100	*0.958728	0.477511
DF-2 - FT-100	*1.79141	0.467457

* denotes a statistically significant difference.

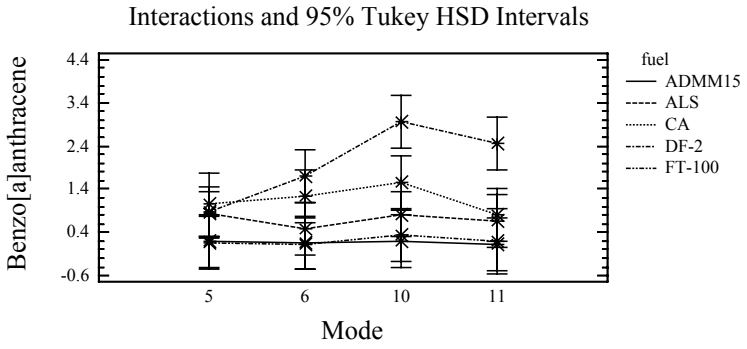
Multiple Range Tests for benzoaan by mode

Method: 95.0 percent Tukey HSD

mode	Count	LS Mean	Homogeneous Groups
5	15	0.612678	X
6	15	0.748889	X
11	14	0.857056	XX
10	16	1.16633	X

Contrast	Difference	+/- Limits
5 - 6	-0.136211	0.383771
5 - 10	*-0.553656	0.377727
5 - 11	-0.244377	0.390563
6 - 10	*-0.417445	0.377727
6 - 11	-0.108166	0.390563
10 - 11	0.309279	0.384626

* denotes a statistically significant difference.



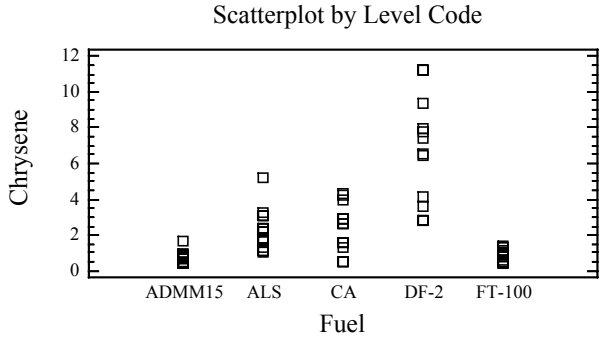
CONCLUSION: The trend in the average benzo[a]anthracene across the modes for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average benzo[a]anthracene at modes 10 and 11 for the DF-2 fuel are significantly different than the other four fuels.

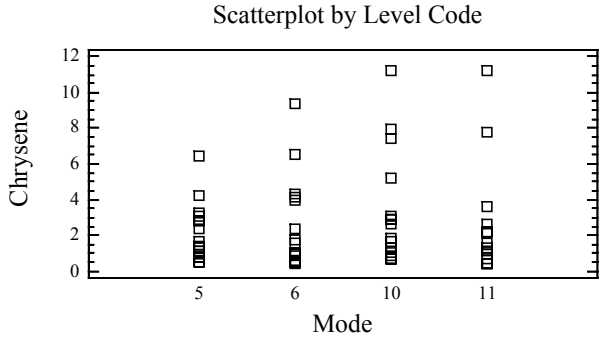
Multifactor ANOVA - Chrysene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: chrysene
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 62



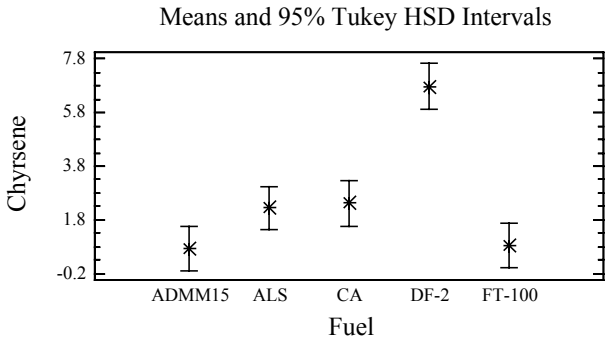


Analysis of Variance for chrysene - Type III Sums of Squares

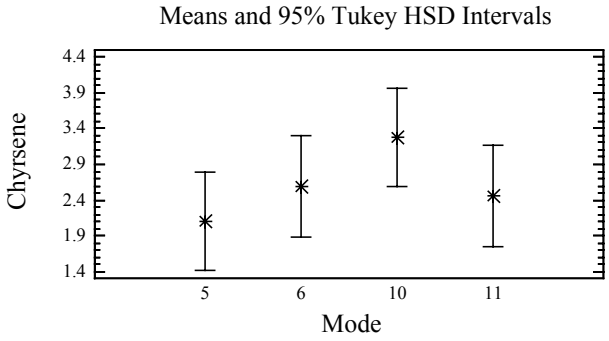
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	289.281	4	72.3202	34.50	0.0000
B:mode	11.5288	3	3.84294	1.83	0.1558
INTERACTIONS					
AB	36.6934	12	3.05779	1.46	0.1788
RESIDUAL	88.0472	42	2.09636		
TOTAL (CORRECTED)	424.358	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average chrysene among the fuels.



CONCLUSION: The average chrysene for the DF-2 fuel is significantly different than the remaining four fuels. Also, the average chrysene for the CA fuel is significantly different than the ADMM15 fuel.



CONCLUSION: There is no significant difference in the average chrysene among the modes.

Multiple Range Tests for chrysene by fuel

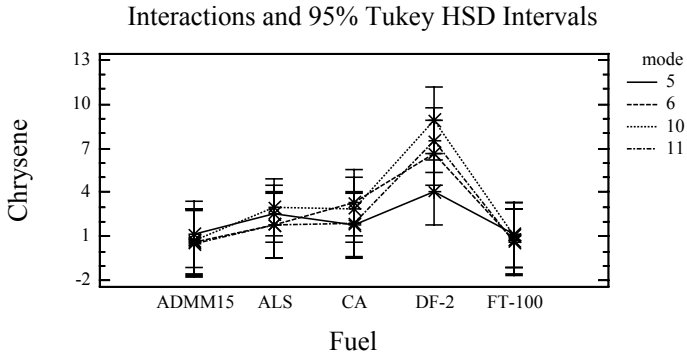
Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	12	0.731573	X
FT-100	12	0.86227	XX
ALS	14	2.24956	XX
CA	12	2.42491	X
DF-2	12	6.77433	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.51799	1.62336
ADMM15 - CA	*-1.69334	1.68464
ADMM15 - DF-2	*-6.04276	1.68464
ADMM15 - FT-100	-0.130697	1.68464
ALS - CA	-0.175346	1.62336
ALS - DF-2	*-4.52476	1.62336
ALS - FT-100	1.38729	1.62336
CA - DF-2	*-4.34942	1.68464
CA - FT-100	1.56264	1.68464
DF-2 - FT-100	*5.91206	1.68464

* denotes a statistically significant difference.

Multiple Range Tests for chrysene by mode

```
---------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
mode            Count     LS Mean           Homogeneous Groups
---------------------------------------------------------------------------------
5               16        2.10097           X
11              15        2.45668           X
6               15        2.59673           X
10              16        3.27974           X
---------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
---------------------------------------------------------------------------------
5 - 6                                     -0.495764            1.39209
5 - 10                                    -1.17877             1.36945
5 - 11                                    -0.355715            1.39209
6 - 10                                    -0.683006            1.39209
6 - 11                                    0.140048             1.41436
10 - 11                                   0.823054             1.39209
---------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



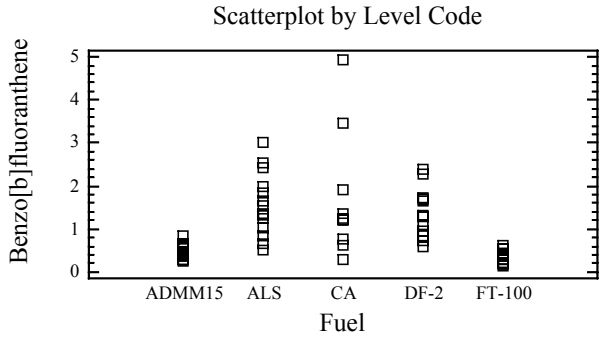
CONCLUSION: There is no significant interaction in the average chrysene among the fuel and mode combinations.

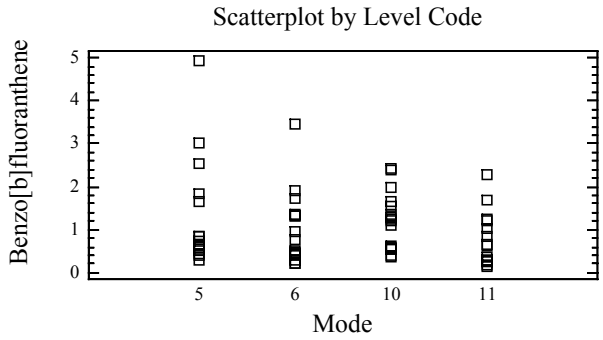
Multifactor ANOVA - Benzo[b]fluoranthene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: benzobfl
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 60



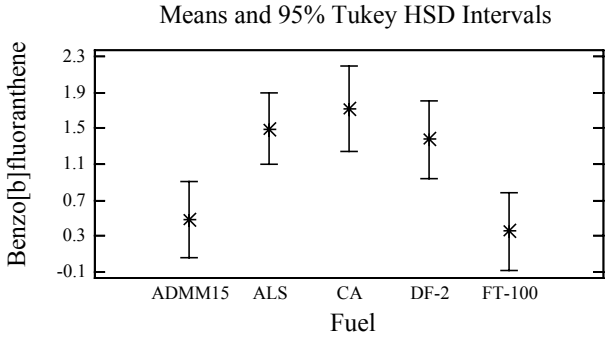


Analysis of Variance for benzobfl - Type III Sums of Squares

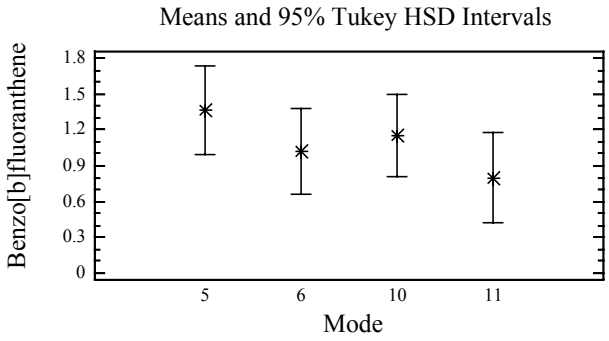
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	18.0149	4	4.50373	8.36	0.0001
B:mode	2.38476	3	0.79492	1.47	0.2359
INTERACTIONS					
AB	6.23245	12	0.519371	0.96	0.4978
RESIDUAL	21.5616	40	0.53904		
TOTAL (CORRECTED)	48.7599	59			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[b]fluoranthene among the fuels.



CONCLUSION: There are two distinct fuel groupings with respect to the average benzo[b]fluoranthene. The CA, ALS, and DF-2 fuels are not significantly different from one another, but are different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another.



CONCLUSION: There is no significant difference in the average benzo[b]fluoranthene among the modes.

Multiple Range Tests for benzobfl by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
FT-100	12	0.348473	X
ADMM15	12	0.48136	X
DF-2	12	1.37735	X
ALS	14	1.49583	X
CA	10	1.71464	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-1.01447	0.824998
ADMM15 - CA	*-1.23328	0.897928
ADMM15 - DF-2	*-0.895986	0.85614
ADMM15 - FT-100	0.132886	0.85614
ALS - CA	-0.218812	0.868285
ALS - DF-2	0.118483	0.824998
ALS - FT-100	*1.14736	0.824998
CA - DF-2	0.337295	0.897928
CA - FT-100	*1.36617	0.897928
DF-2 - FT-100	*1.02887	0.85614

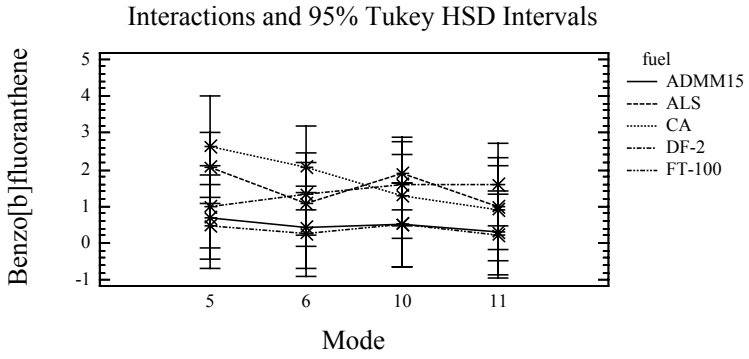
* denotes a statistically significant difference.

Multiple Range Tests for benzobfl by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups
11	14	0.795638	X
6	15	1.02147	X
10	16	1.15339	X
5	15	1.36363	X

Contrast	Difference	+/- Limits
5 - 6	0.342159	0.718667
5 - 10	0.210239	0.707349
5 - 11	0.567988	0.731388
6 - 10	-0.13192	0.707349
6 - 11	0.225829	0.731388
10 - 11	0.357749	0.72027

* denotes a statistically significant difference.



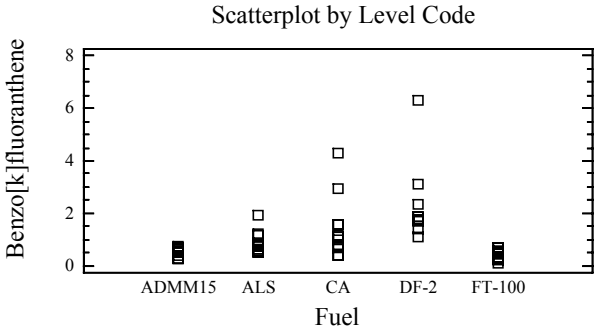
CONCLUSION: There is no significant interaction in the average benzo[b]fluoranthene among the fuel and mode combinations.

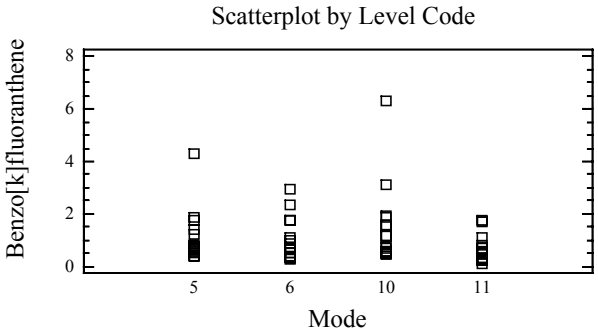
Multifactor ANOVA - Benzo[k]fluoranthene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: benzokfl
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 61



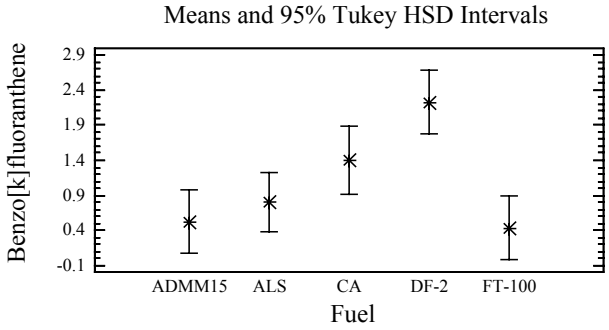


Analysis of Variance for benzokfl - Type III Sums of Squares

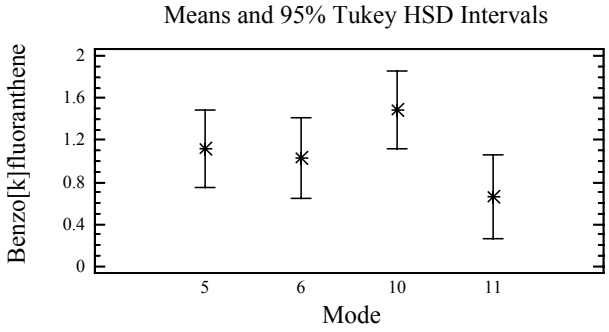
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	26.7077	4	6.67693	10.92	0.0000
B:mode	4.97265	3	1.65755	2.71	0.0574
INTERACTIONS					
AB	7.48971	12	0.624142	1.02	0.4490
RESIDUAL	25.0787	41	0.611676		
TOTAL (CORRECTED)	64.3624	60			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[k]fluoranthene among the fuels and modes.



CONCLUSION: The average benzo[k]fluoranthene for the DF-2 fuel is significantly different than the ADMM15, ALS, and FT-100 fuels. The average benzo[k]fluoranthene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another. Also, the average benzo[k]fluoranthene for the CA fuel is significantly different than the FT-100 fuel.



CONCLUSION: The average benzo[k]fluoranthene for mode 10 is significantly different than mode 11.

Multiple Range Tests for benzokfl by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
FT-100	12	0.429788	X
ADMM15	12	0.521305	XX
ALS	14	0.79762	XX
CA	11	1.39424	XX
DF-2	12	2.22632	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.276314	0.87783
ADMM15 - CA	-0.872935	0.931441
ADMM15 - DF-2	*-1.70502	0.910967
ADMM15 - FT-100	0.0915172	0.910967
ALS - CA	-0.596621	0.899059
ALS - DF-2	*-1.4287	0.87783
ALS - FT-100	0.367832	0.87783
CA - DF-2	-0.832082	0.931441
CA - FT-100	*0.964452	0.931441
DF-2 - FT-100	*1.79653	0.910967

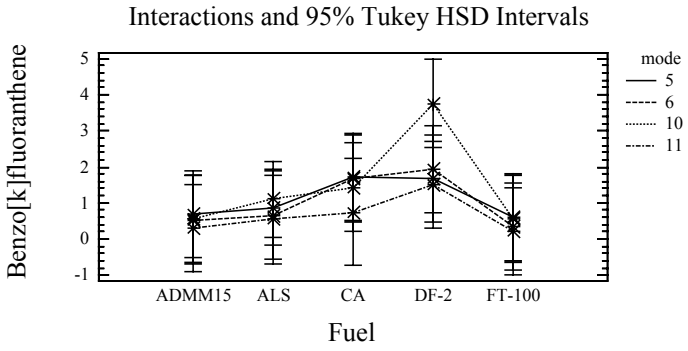
* denotes a statistically significant difference.

Multiple Range Tests for benzokfl by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups
11	14	0.665197	X
6	15	1.02958	XX
5	16	1.11709	XX
10	16	1.48356	X

Contrast	Difference	+/- Limits
5 - 6	0.0875137	0.75271
5 - 10	-0.366465	0.74047
5 - 11	0.451894	0.76646
6 - 10	-0.453979	0.75271
6 - 11	0.36438	0.778291
10 - 11	*0.818359	0.76646

* denotes a statistically significant difference.



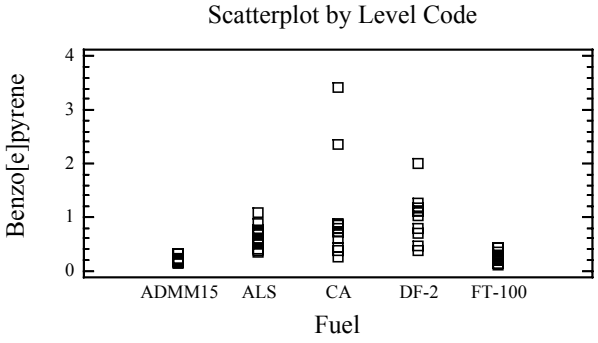
CONCLUSION: There is no significant interaction in the average benzo[k]fluoranthene among the fuel and mode combinations.

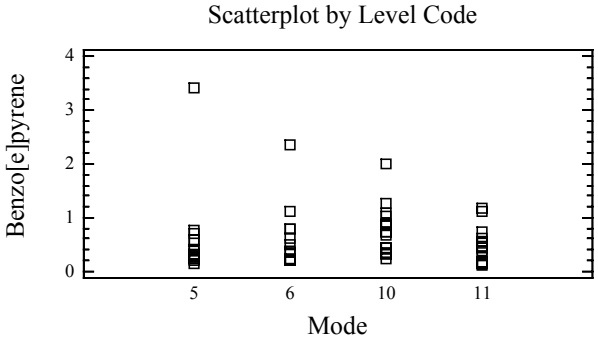
Multifactor ANOVA - Benzo[e]pyrene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: benzoepy
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 57



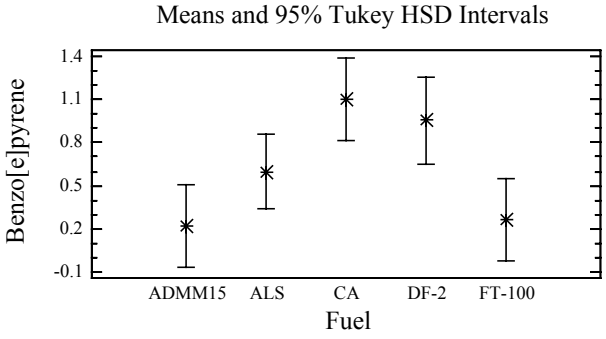


Analysis of Variance for benzoepy - Type III Sums of Squares

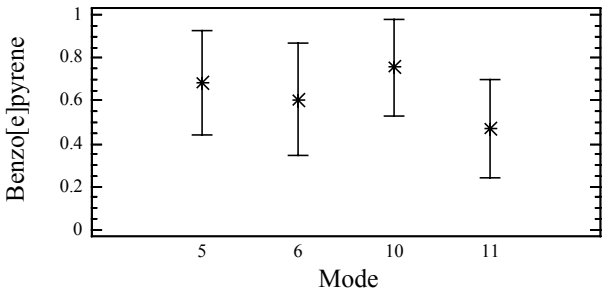
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	6.67906	4	1.66977	7.66	0.0001
B:mode	0.67039	3	0.223463	1.02	0.3929
INTERACTIONS					
AB	3.16355	12	0.26363	1.21	0.3137
RESIDUAL	8.07046	37	0.21812		
TOTAL (CORRECTED)	18.3948	56			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[e]pyrene among the fuels.



CONCLUSION: The average benzo[e]pyrene for the CA and DF-2 fuels are significantly different than the FT-100 and ADMM15 fuels, but not significantly different from one another. Also, the average benzo[e]pyrene for the ALS fuel is not significantly different from the remaining four fuels.



CONCLUSION: There is no significant difference in the average benzo[e]pyrene among the modes.

Multiple Range Tests for benzoepy by fuel

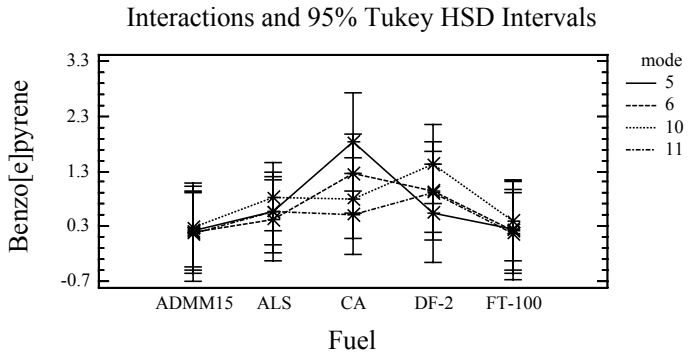
Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	11	0.221489	X
FT-100	11	0.262074	X
ALS	14	0.599731	XX
DF-2	10	0.957389	X
CA	11	1.10608	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.378242	0.539519
ADMM15 - CA	*-0.884591	0.570973
ADMM15 - DF-2	*-0.7359	0.585073
ADMM15 - FT-100	-0.0405851	0.570973
ALS - CA	-0.506349	0.539519
ALS - DF-2	-0.357658	0.55442
ALS - FT-100	0.337657	0.539519
CA - DF-2	0.148691	0.585073
CA - FT-100	*0.844006	0.570973
DF-2 - FT-100	*0.695315	0.585073

* denotes a statistically significant difference.

Multiple Range Tests for benzoepy by mode

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
mode            Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
11              15        0.471842          X
6               12        0.60491           X
5               14        0.68533           X
10              16        0.755329          X
-------------------------------------------------------------------------------
Contrast                                    Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                       0.0804202            0.49425
5 - 10                                      -0.0699989           0.459781
5 - 11                                      0.213488             0.466878
6 - 10                                      -0.150419            0.479781
6 - 11                                      0.133068             0.486587
10 - 11                                     0.283487             0.451533
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



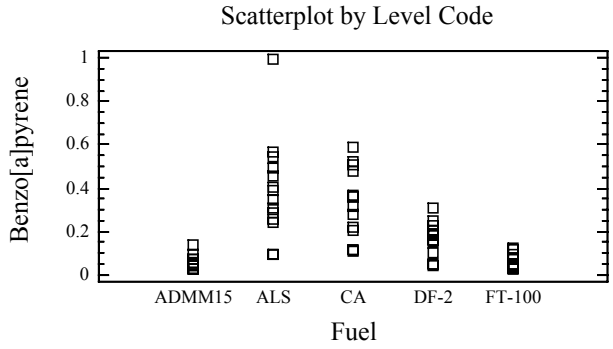
CONCLUSION: There is no significant interaction in the average benzo[e]pyrene among the fuel and mode combinations.

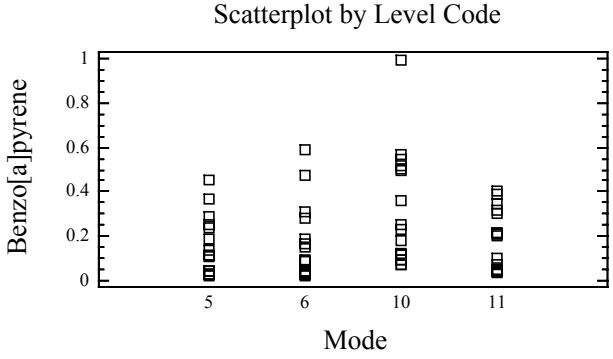
Multifactor ANOVA - Benzo[a]pyrene (µg/kW-hr) Soluble PAH
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: benzoapy
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 62



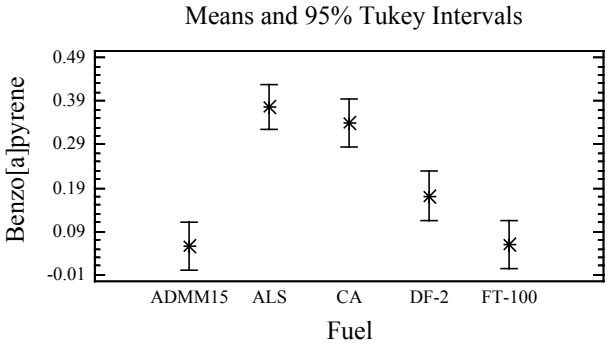


Analysis of Variance for benzoapy - Type III Sums of Squares

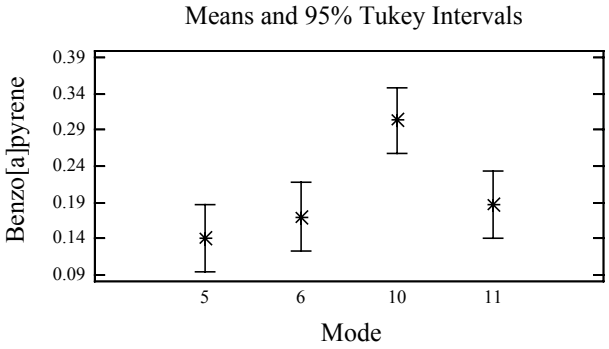
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1.15306	4	0.288266	31.27	0.0000
B:mode	0.242293	3	0.0807643	8.76	0.0001
INTERACTIONS					
AB	0.373391	12	0.0311159	3.37	0.0017
RESIDUAL	0.387228	42	0.00921972		
TOTAL (CORRECTED)	2.27649	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[a]pyrene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average benzo[a]pyrene for the CA and ALS fuels are significantly different from the remaining three fuels but not different from one another. The average benzo[a]pyrene for the ADMM15 fuel is significantly different from the DF-2 fuel, but not significantly different from the FT-100 fuel.



CONCLUSION: The average benzo[a]pyrene for mode 10 is significantly different from the remaining three modes.

Multiple Range Tests for benzoapy by fuel

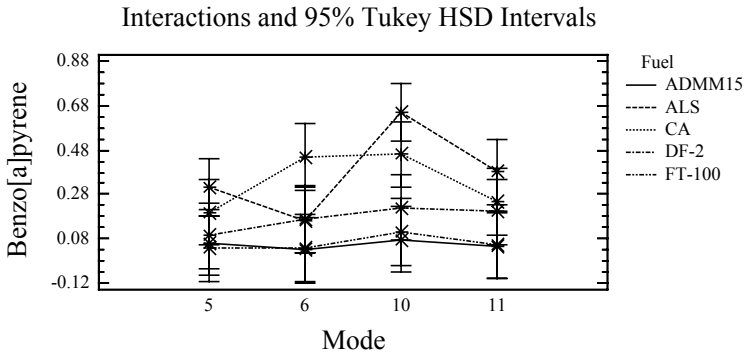
Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	12	0.0549743	X
FT-100	12	0.0598222	XX
DF-2	12	0.171345	X
CA	12	0.338816	X
ALS	14	0.376119	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.321145	0.107656
ADMM15 - CA	*-0.283842	0.11172
ADMM15 - DF-2	*-0.116371	0.11172
ADMM15 - FT-100	-0.00484792	0.11172
ALS - CA	0.0373028	0.107656
ALS - DF-2	*0.204774	0.107656
ALS - FT-100	*0.316297	0.107656
CA - DF-2	*0.167471	0.11172
CA - FT-100	*0.278994	0.11172
DF-2 - FT-100	0.111523	0.11172

* denotes a statistically significant difference.

Multiple Range Tests for benzoapy by mode

```
------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
mode           Count     LS Mean           Homogeneous Groups
------------------------------------------------------------------------------
5              16        0.140402          X
6              15        0.170284          X
11             15        0.18635           X
10             16        0.303826           X
------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
------------------------------------------------------------------------------
5 - 6                                      -0.029882           0.0923192
5 - 10                                    *-0.163424           0.0908179
5 - 11                                     -0.0459479          0.0923192
6 - 10                                    *-0.133542           0.0923192
6 - 11                                     -0.0160659          0.0937964
10 - 11                                   *0.117476            0.0923192
------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



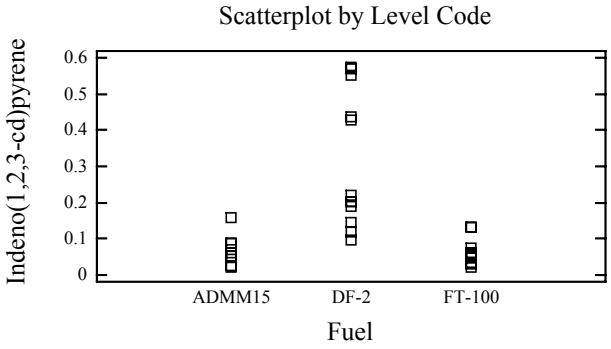
CONCLUSION: The trend in the average benzo[a]pyrene across the modes for the ALS fuel is significantly different than the trends for the remaining four fuels. Also, the average benzo[a]pyrene for the CA fuel is significantly different than the other fuels at mode 6.

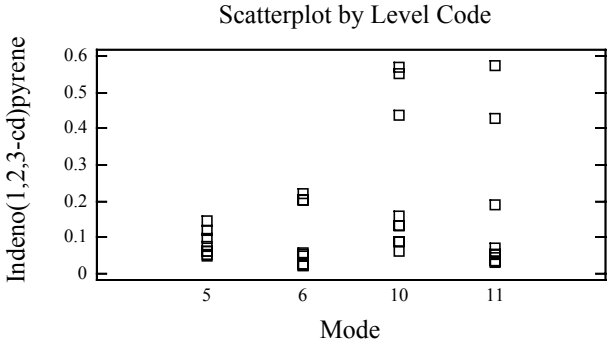
Multifactor ANOVA - Indeno(1,2,3-cd)pyrene (µg/kW-hr) Soluble PAH
LPP and DF-2, FT-100, ADMM15 Fuels Only Modes 5,6,10,11

Analysis Summary

Dependent variable: indeno
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 35



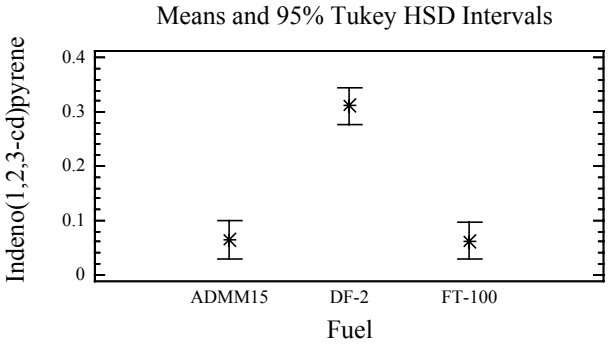


Analysis of Variance for indeno - Type III Sums of Squares

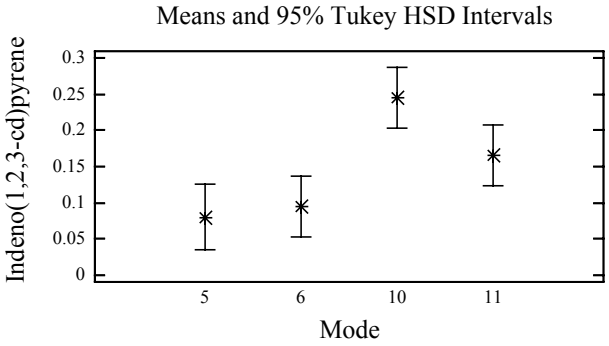
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.480412	2	0.240206	57.54	0.0000
B:mode	0.15027	3	0.0500901	12.00	0.0001
INTERACTIONS					
AB	0.151044	6	0.0251739	6.03	0.0007
RESIDUAL	0.0960184	23	0.00417471		
TOTAL (CORRECTED)	0.888817	34			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average indeno(1,2,3-cd)pyrene among the fuels, modes, and fuel*mode interaction.



CONCLUSION: The average indeno(1,2,3-cd)pyrene for the DF-2 fuel is significantly different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another with respect to the average indeno(1,2,3-cd)pyrene.



CONCLUSION: The average indeno(1,2,3-cd)pyrene for mode 10 is significantly different than modes 5 and 6. Mode 11 is not significantly different from the remaining three modes with respect to the average indeno(1,2,3-cd)pyrene.

Multiple Range Tests for indeno by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
FT-100	12	0.062351	X
ADMM15	11	0.0651034	X
DF-2	12	0.31108	X

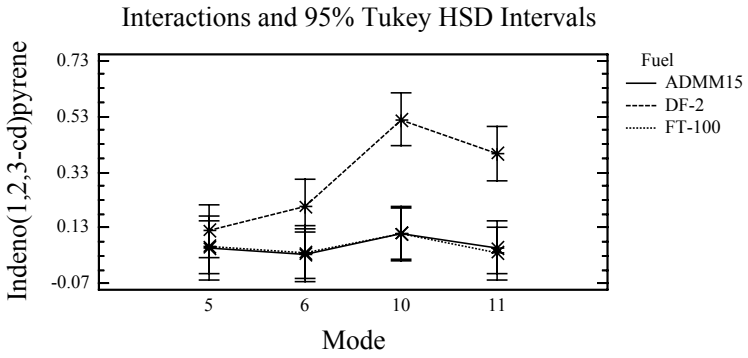
Contrast	Difference	+/- Limits
ADMM15 - DF-2	*-0.245977	0.0675663
ADMM15 - FT-100	0.00275231	0.0675663
DF-2 - FT-100	*0.248729	0.0660811

* denotes a statistically significant difference.

Multiple Range Tests for indeno by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups
5	8	0.0794008	X
6	9	0.0947125	X
11	9	0.164935	XX

```
10             9         0.245665           X
-------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                      -0.0153117           0.0869054
5 - 10                                    *-0.166264            0.0869054
5 - 11                                     -0.085534            0.0869054
6 - 10                                    *-0.150952            0.0843106
6 - 11                                     -0.0702223           0.0843106
10 - 11                                    0.0807299            0.0843106
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



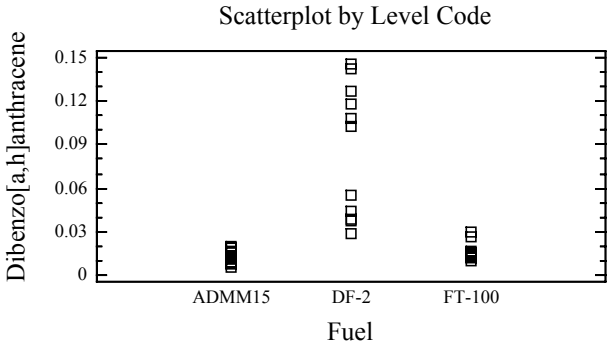
CONCLUSION: The trend in the average indeno(1,2,3-cd)pyrene across the modes for the DF-2 fuel is significantly different than the trends in the remaining two fuels. The average indeno(1,2,3-cd)pyrene at modes 10 and 11 for the DF-2 fuel are significantly different than the ADMM15 and FT-100 fuels.

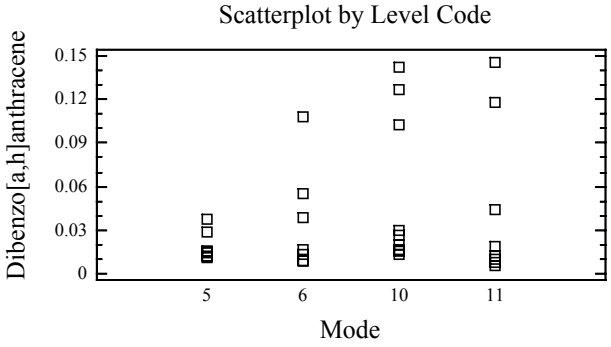
Multifactor ANOVA - Dibenzo[a,h]anthracene (µg/kW-hr) Soluble PAH
LPP and DF-2, FT-100, ADMM15 Fuels Only Modes 5,6,10,11

Analysis Summary

Dependent variable: dibenzo
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 31



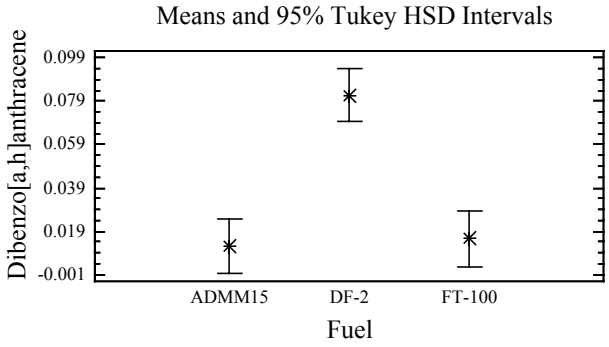


Analysis of Variance for dibenzo - Type III Sums of Squares

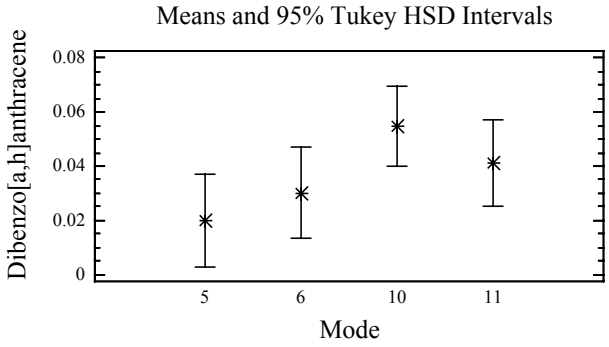
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	0.0316789	2	0.0158394	32.39	0.0000
B:mode	0.00516132	3	0.00172044	3.52	0.0351
INTERACTIONS					
AB	0.00710011	6	0.00118335	2.42	0.0658
RESIDUAL	0.00929022	19	0.000488959		
TOTAL (CORRECTED)	0.0581359	30			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average dibenzo[a,h]anthracene among the fuels and modes.



CONCLUSION: The average dibenzo[a,h]anthracene for the DF-2 fuel is significantly different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average dibenzo[a,h]anthracene for mode 10 is significantly different from mode 5. Modes 6 and 11 are not significantly different from one another or the other two modes.

Multiple Range Tests for dibenzo by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
ADMM15	10	0.0121819	X
FT-100	10	0.0155898	X
DF-2	11	0.0817954	X

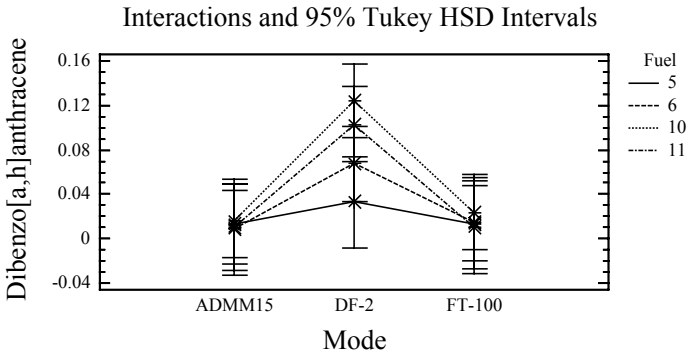
Contrast	Difference	+/- Limits
ADMM15 - DF-2	*-0.0696135	0.0245556
ADMM15 - FT-100	-0.00340796	0.0251335
DF-2 - FT-100	*0.0662056	0.0245556

* denotes a statistically significant difference.

Multiple Range Tests for dibenzo by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups
5	7	0.0199922	X
6	7	0.0302323	XX
11	8	0.0412534	XX

```
10             9         0.0546116          X
-------------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
-------------------------------------------------------------------------------
5 - 6                                      -0.0102401           0.0332468
5 - 10                                    *-0.0346194           0.0313454
5 - 11                                     -0.0212612           0.0321911
6 - 10                                     -0.0243793           0.0313454
6 - 11                                     -0.0110211           0.0321911
10 - 11                                    0.0133582            0.0302233
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



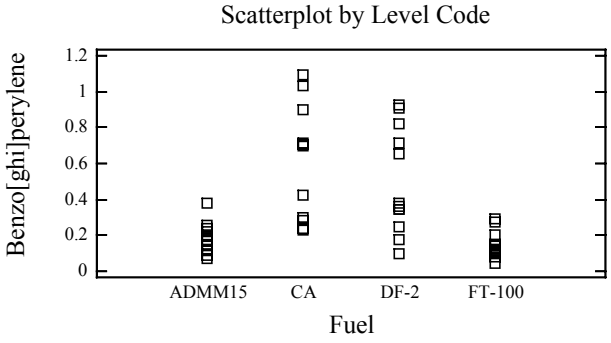
CONCLUSION: There is no significant interaction in the average dibenzo[a,h]anthracene among the fuel and mode combinations.

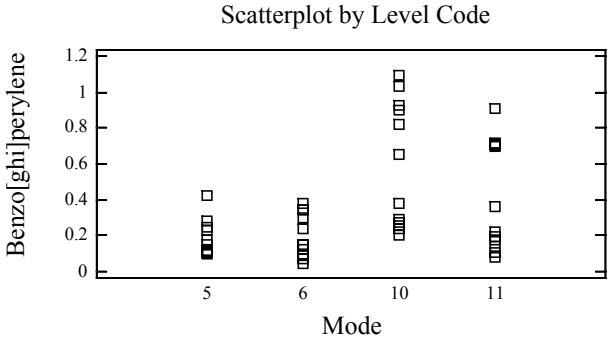
Multifactor ANOVA - Benzo[ghi]perylene (µg/kW-hr) Soluble PAH
LPP and CA, DF-2, FT-100, ADMM15 Fuels Only Modes 5,6,10,11

Analysis Summary

Dependent variable: benzogpe
Factors:
fuel
mode
Selection variable: mode<12

Number of complete cases: 46



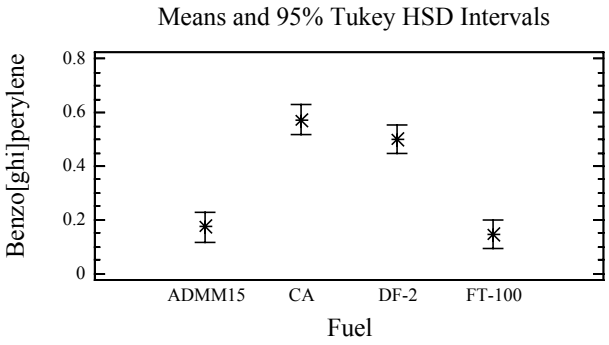


Analysis of Variance for benzogpe - Type III Sums of Squares

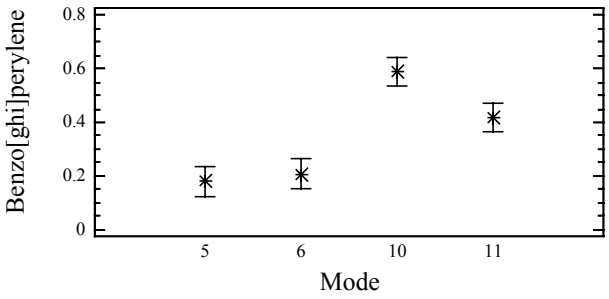
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1.61627	3	0.538758	58.74	0.0000
B:mode	1.26649	3	0.422165	46.03	0.0000
INTERACTIONS					
AB	0.581746	9	0.0646384	7.05	0.0000
RESIDUAL	0.275134	30	0.00917113		
TOTAL (CORRECTED)	3.89934	45			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[ghi]perylene among the fuels, modes and fuel*mode interaction.



CONCLUSION: There are two distinct fuel groupings with respect to the average benzo[ghi]perylene. The CA and DF-2 fuels are not significantly different from one another, but are different from the remaining two fuels. The ADMM15 and FT-100 fuels are not significantly different from one another.



CONCLUSION: There are three distinct mode groupings with respect to the average benzo[ghi]perylene. Modes 10 and 11 are significantly different from one another and the remaining two modes. Modes 5 and 6 are not significantly different from one another, but are significantly different than the other two modes.

Multiple Range Tests for benzogpe by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
FT-100	12	0.147474	X
ADMM15	11	0.174669	X
DF-2	12	0.497732	X
CA	11	0.573893	X

Contrast	Difference	+/- Limits
ADMM15 - CA	*-0.399224	0.111054
ADMM15 - DF-2	*-0.323063	0.108716
ADMM15 - FT-100	0.0271954	0.108716
CA - DF-2	0.0761614	0.108716
CA - FT-100	*0.426419	0.108716
DF-2 - FT-100	*0.350258	0.106326

* denotes a statistically significant difference.

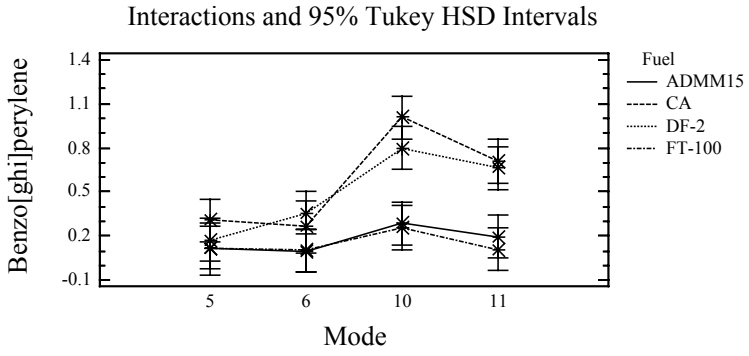
Multiple Range Tests for benzogpe by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups

5	11	0.179922	X	
6	11	0.206259	X	
11	12	0.419015	X	
10	12	0.588573	X	

Contrast	Difference	+/- Limits
5 - 6	-0.0263369	0.111054
5 - 10	*-0.408651	0.108716
5 - 11	*-0.239093	0.108716
6 - 10	*-0.382314	0.108716
6 - 11	*-0.212756	0.108716
10 - 11	*0.169558	0.106326

* denotes a statistically significant difference.



CONCLUSION: The trend in the average benzo[ghi]perylene across the modes for the DF-2 and CA fuels is significantly different than the trends in the remaining two fuels. The average benzo[ghi]perylene at modes 10 and 11 for the DF-2 and CA fuels are significantly different than the ADMM15 and FT-100 fuels.

APPENDIX F

ANOVA for Pilot Condition

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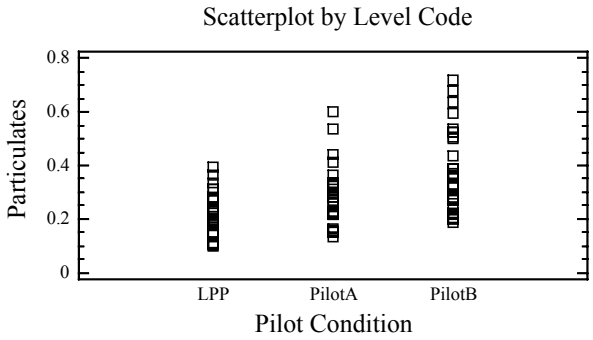
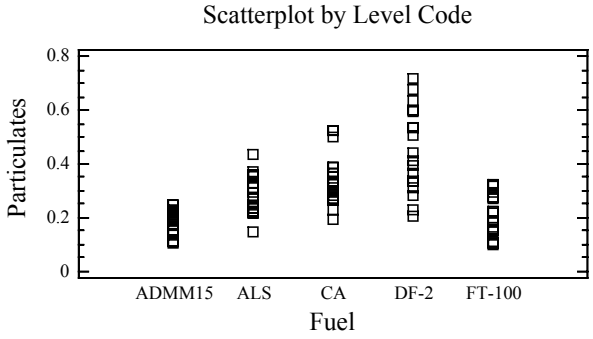
Multifactor ANOVA - Total Particulates (g/kW-hr)
Three Pilot Conditions Modes 10 and 11

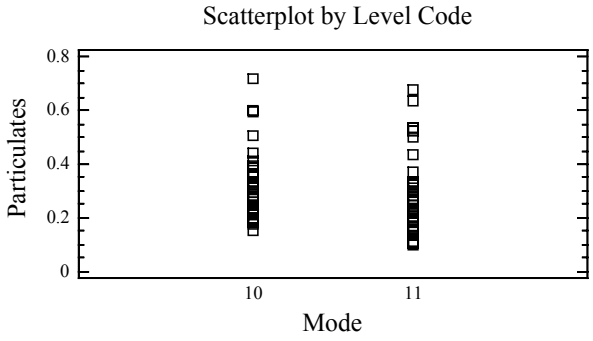
Analysis Summary

Dependent variable: PARTIC
Factors:
COND
FUEL
MODE

Number of complete cases: 91







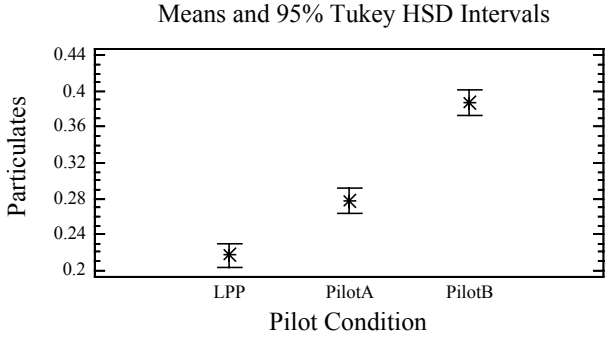
Analysis of Variance for PARTIC - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	0.455465	2	0.227733	114.53	0.0000
B:FUEL	0.835454	4	0.208864	105.04	0.0000
C:MODE	0.0313438	1	0.0313438	15.76	0.0002

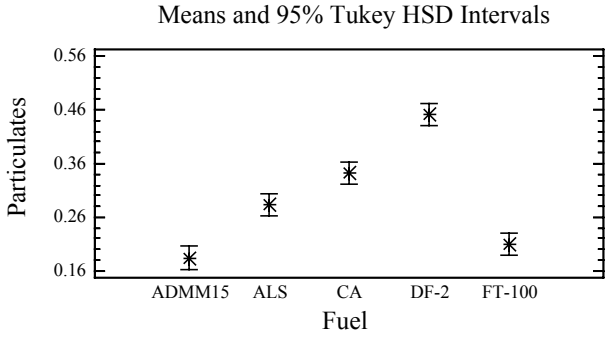
INTERACTIONS					
AB	0.105563	8	0.0131954	6.64	0.0000
AC	0.0543366	2	0.0271683	13.66	0.0000
BC	0.0110984	4	0.0027746	1.40	0.2462
ABC	0.0140696	8	0.0017587	0.88	0.5349
RESIDUAL	0.121298	61	0.00198849		
TOTAL (CORRECTED)	1.62565	90			

All F-ratios are based on the residual mean square error.

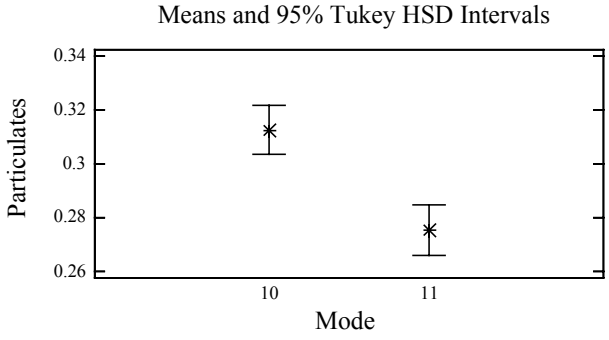
CONCLUSIONS: Statistically significant differences in the average particulates among the fuels, modes, pilot conditions, and some two-way interactions.



CONCLUSION: The average particulates at all three pilot conditions are significantly different from one another.



CONCLUSION: The average particulates for the ALS, CA, and DF-2 fuels are significantly different from each other and the remaining two fuels. The average particulates for the ADMM15 and FT-100 fuels are not significantly different from one another.



CONCLUSION: Modes 10 and 11 are significantly different from one another with respect to the average particulates.

Multiple Range Tests for PARTIC by COND

Method: 95.0 percent Tukey HSD

COND	Count	LS Mean	Homogeneous Groups
LPP	31	0.216564	X
PilotA	30	0.277749	X
PilotB	30	0.387645	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-0.0611853	0.0274365
LPP - PilotB	*-0.171081	0.0274365
PilotA - PilotB	*-0.109896	0.0276605

* denotes a statistically significant difference.

Multiple Range Tests for PARTIC by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	0.184316	X
FT-100	18	0.209423	X
ALS	19	0.28249	X
CA	18	0.342372	X
DF-2	18	0.451328	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.098174	0.041231
ADMM15 - CA	*-0.158056	0.0417844
ADMM15 - DF-2	*-0.267012	0.0417844
ADMM15 - FT-100	-0.0251069	0.0417844
ALS - CA	*-0.0598823	0.041231
ALS - DF-2	*-0.168838	0.041231
ALS - FT-100	*0.0730671	0.041231
CA - DF-2	*-0.108956	0.0417844
CA - FT-100	*0.132949	0.0417844
DF-2 - FT-100	*0.241905	0.0417844

* denotes a statistically significant difference.

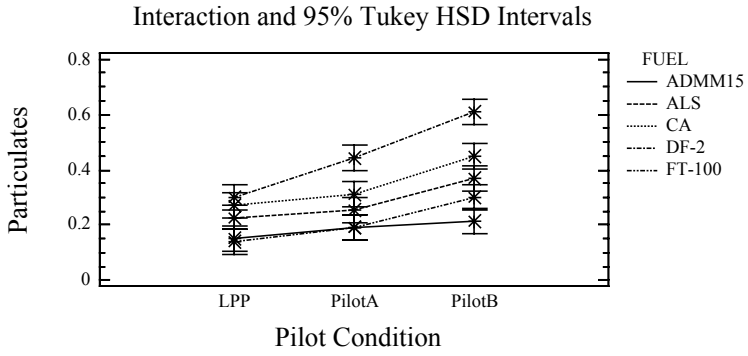
Multiple Range Tests for PARTIC by MODE

Method: 95.0 percent Tukey HSD

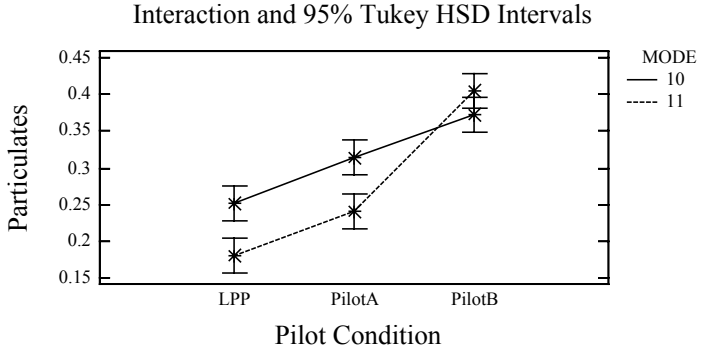
MODE	Count	LS Mean	Homogeneous Groups
11	45	0.275402	X
10	46	0.31257	X

Contrast	Difference	+/- Limits
10 - 11	*0.0371679	0.0186959

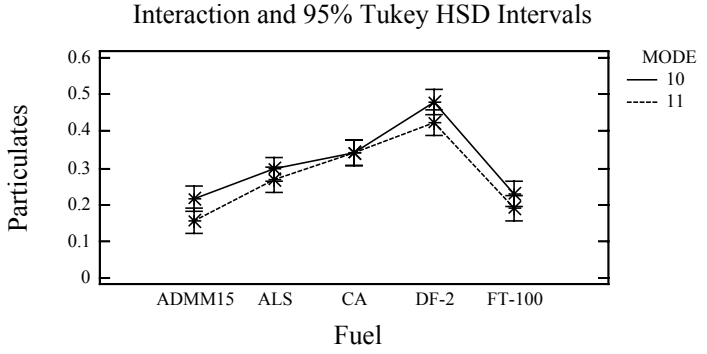
* denotes a statistically significant difference.



CONCLUSION: The trend in the average particulates across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average particulates for the DF-2 at the Pilot B condition is significantly different than the other four fuels; however, there is not a significant difference at the LPP condition.



CONCLUSION: There is a significant interaction among the mode and pilot condition combinations. While the average particulates at mode 11 is significantly different at the LPP and Pilot A conditions, there is no significant difference at the Pilot B condition.



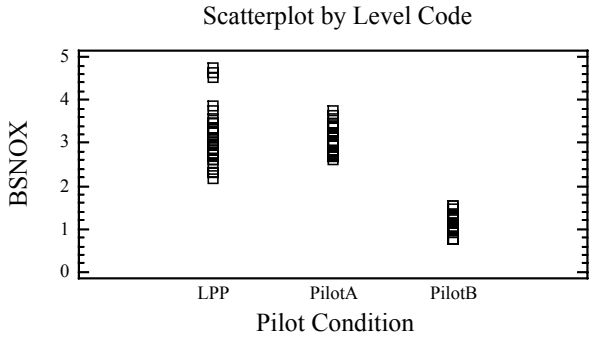
CONCLUSION: There is no significant interaction in the average particulates among the fuel and mode combinations.

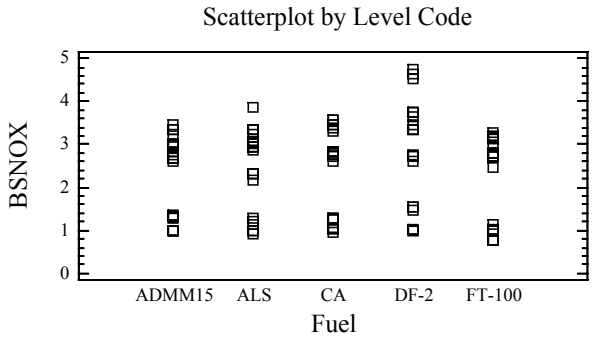
Multifactor ANOVA - BSNOX (g/kW-hr)
Three Pilot Conditions Modes 10 and 11

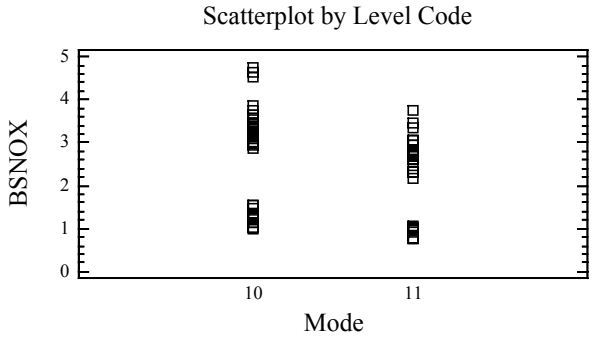
Analysis Summary

Dependent variable: BSNOX
Factors:
COND
FUEL
MODE

Number of complete cases: 91







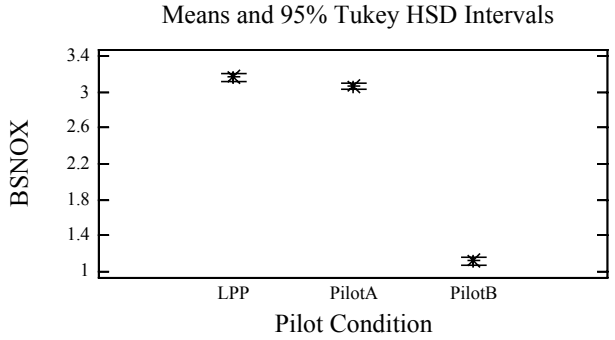
Analysis of Variance for BSNOX - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	80.9912	2	40.4956	2053.21	0.0000
B:FUEL	3.63542	4	0.908855	46.08	0.0000
C:MODE	6.69082	1	6.69082	339.24	0.0000

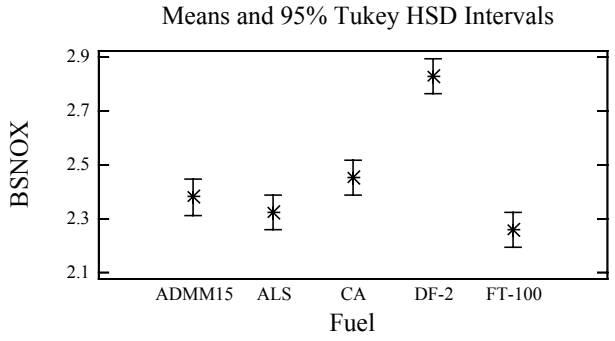
INTERACTIONS					
AB	3.97541	8	0.496927	25.20	0.0000
AC	0.761949	2	0.380974	19.32	0.0000
BC	0.595608	4	0.148902	7.55	0.0001
ABC	0.264499	8	0.0330624	1.68	0.1226
RESIDUAL	1.2031	61	0.019723		
TOTAL (CORRECTED)	98.0747	90			

All F-ratios are based on the residual mean square error.

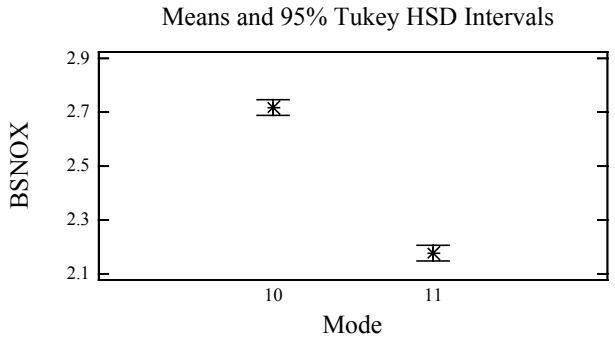
CONCLUSION: Statistically significant differences in the average BSNOX among the fuels, modes, pilot conditions, and two-way interactions.



CONCLUSION: All three pilot conditions are significantly different from one another with respect to the average BSNOX.



CONCLUSION: The average BSNOX for the DF-2 fuel is significantly different than the remaining four fuels. The CA fuel has significantly different average BSNOX than the ALS and FT-100 fuels. Also, the FT-100, CA, and ADMM15 fuels are not significantly different from one another.



CONCLUSION: Modes 10 and 11 are significantly different from one another with respect to the average BSNOX.

Multiple Range Tests for BSNOX by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
PilotB	30	1.11171	X
PilotA	30	3.06692	X
LPP	31	3.16761	X

Contrast	Difference	+/- Limits
LPP - PilotA	*0.100688	0.0864081
LPP - PilotB	*2.0559	0.0864081
PilotA - PilotB	*1.95521	0.0871135

* denotes a statistically significant difference.

Multiple Range Tests for BSNOX by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	2.25888	X
ALS	19	2.32239	X
ADMM15	18	2.37957	XX
CA	18	2.45407	X
DF-2	18	2.82881	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	0.0571797	0.129852
ADMM15 - CA	-0.0745012	0.131595
ADMM15 - DF-2	*-0.449242	0.131595
ADMM15 - FT-100	0.120692	0.131595
ALS - CA	*-0.131681	0.129852
ALS - DF-2	*-0.506422	0.129852
ALS - FT-100	0.0635123	0.129852
CA - DF-2	*-0.374741	0.131595
CA - FT-100	*0.195193	0.131595
DF-2 - FT-100	*0.569934	0.131595

* denotes a statistically significant difference.

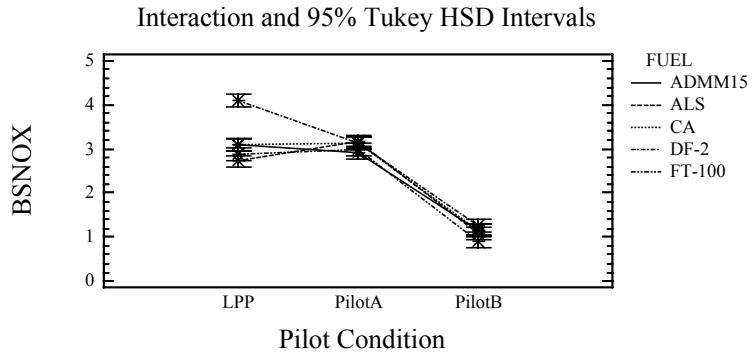
Multiple Range Tests for BSNOX by MODE

Method: 95.0 percent Tukey HSD

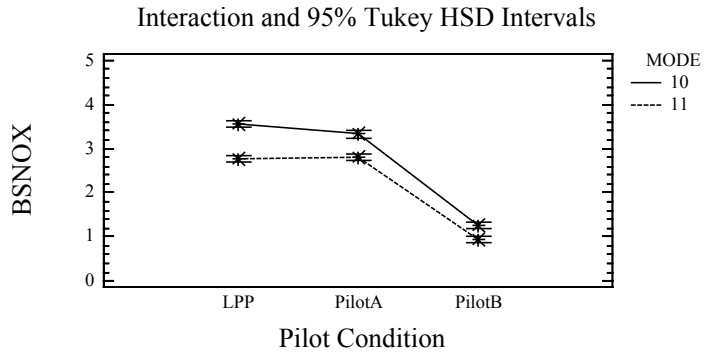
MODE	Count	LS Mean	Homogeneous Groups
11	45	2.17722	X
10	46	2.72026	X

Contrast	Difference	+/- Limits
10 - 11	*0.543039	0.0588805

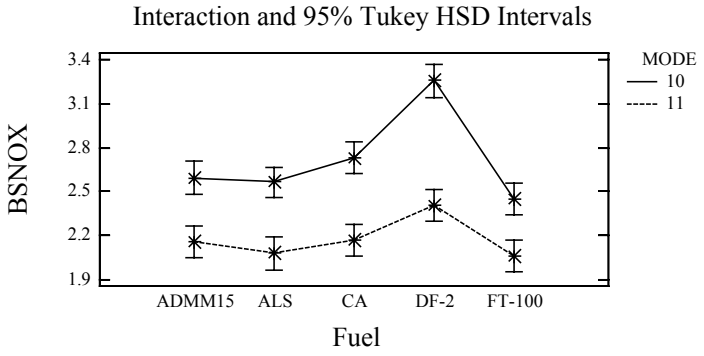
* denotes a statistically significant difference.



CONCLUSION: The average BSNOX for the DF-2 fuel is significantly different than the remaining four fuels at the LPP condition. This trend does not exist at the Pilot A or Pilot B conditions.



CONCLUSION: A significant interaction exists between the pilot condition and the modes. The difference in the average BSNOX between modes 10 and 11 at the LPP condition is larger than the difference at the Pilot B condition.



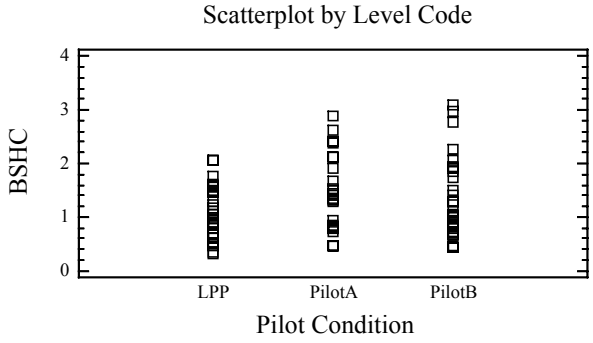
CONCLUSION: A significant interaction exists between the mode and fuel levels. The difference in the average BSNOX between modes 10 and 11 is the largest at the DF-2 fuel and the smallest at the FT-100 fuel.

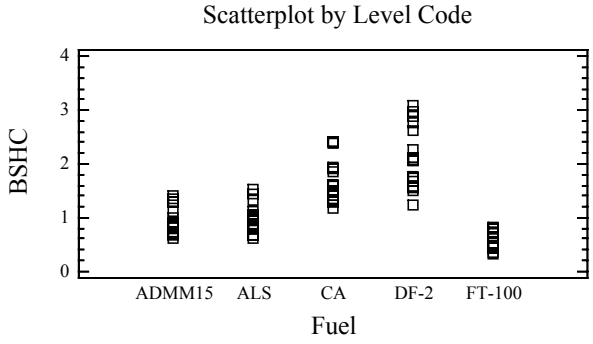
Multifactor ANOVA - BSHC (g/kW-hr)
Three Pilot Conditions Modes 10 and 11

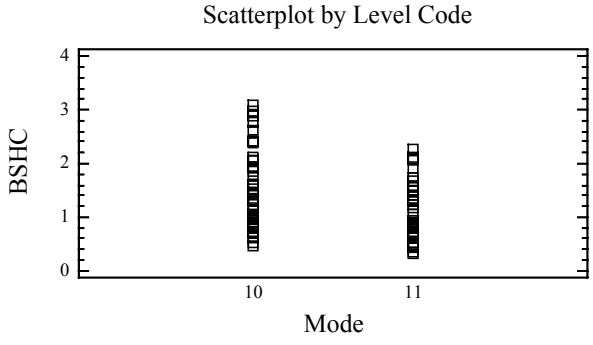
Analysis Summary

Dependent variable: BSHC
Factors:
COND
FUEL
MODE

Number of complete cases: 91







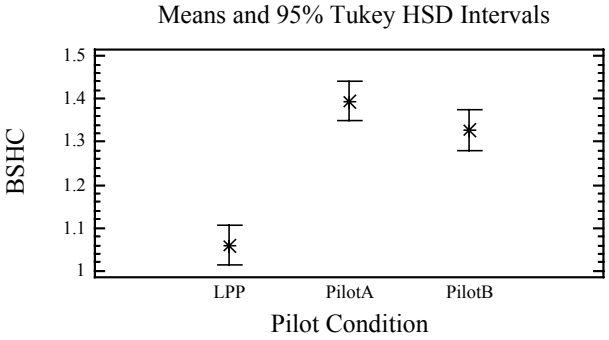
Analysis of Variance for BSHC - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	1.91308	2	0.956538	41.95	0.0000

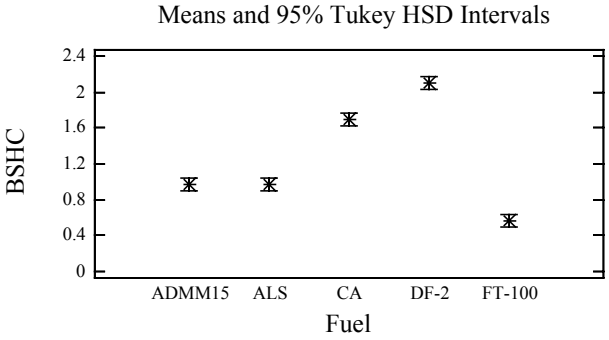
B:FUEL	28.1562	4	7.03905	308.73	0.0000
C:MODE	4.6382	1	4.6382	203.43	0.0000
INTERACTIONS					
AB	1.41323	8	0.176654	7.75	0.0000
AC	0.53378	2	0.26689	11.71	0.0000
BC	0.647364	4	0.161841	7.10	0.0001
ABC	0.165542	8	0.0206928	0.91	0.5163
RESIDUAL	1.39082	61	0.0228003		
TOTAL (CORRECTED)	38.795	90			

All F-ratios are based on the residual mean square error.

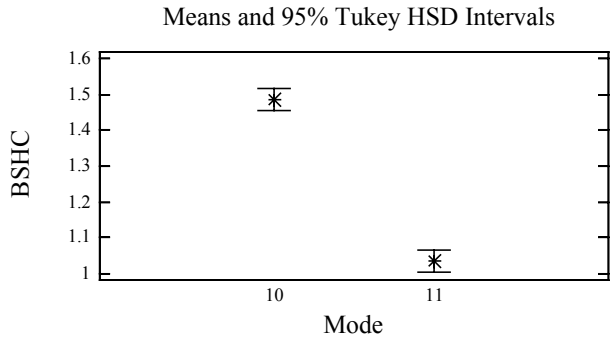
CONCLUSION: Statistically significant differences in the average BSHC among the fuels, modes, pilot conditions, and interactions.



CONCLUSION: Average BSHC at the Pilot A and Pilot B conditions are not significantly different from one another, but both are different from the average BSHC at the LPP condition.



CONCLUSION: The average BSHC at the FT-100, CA, and DF-2 fuels are all significantly different from one another. The average BSHC for the ADMM15 and ALS fuels are not significantly different from one another, but are different from the other 3 fuels.



CONCLUSION: The average BSHC at modes 10 and 11 are significantly different from one another.

Multiple Range Tests for BSHC by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	1.05976	X
PilotB	30	1.32712	X
PilotA	30	1.39471	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-0.334943	0.0929048
LPP - PilotB	*-0.267355	0.0929048
PilotA - PilotB	0.0675875	0.0936632

* denotes a statistically significant difference.

Multiple Range Tests for BSHC by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	0.565613	X
ALS	19	0.965014	X
ADMM15	18	0.971421	X
CA	18	1.69051	X
DF-2	18	2.1101	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	0.0064071	0.139615
ADMM15 - CA	*-0.719086	0.141489
ADMM15 - DF-2	*-1.13868	0.141489
ADMM15 - FT-100	*0.405808	0.141489
ALS - CA	*-0.725493	0.139615
ALS - DF-2	*-1.14508	0.139615
ALS - FT-100	*0.399401	0.139615
CA - DF-2	*-0.419591	0.141489
CA - FT-100	*1.12489	0.141489
DF-2 - FT-100	*1.54448	0.141489

* denotes a statistically significant difference.

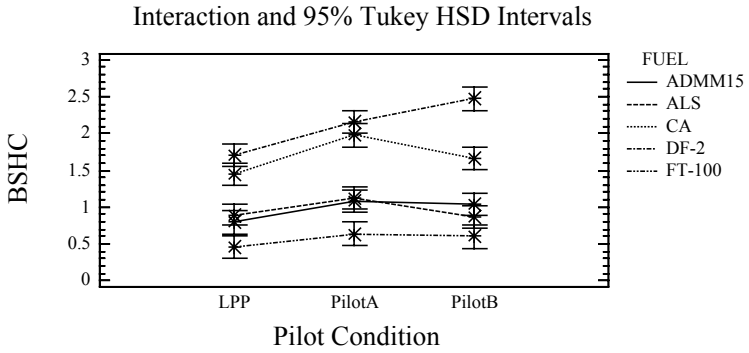
Multiple Range Tests for BSHC by MODE

Method: 95.0 percent Tukey HSD

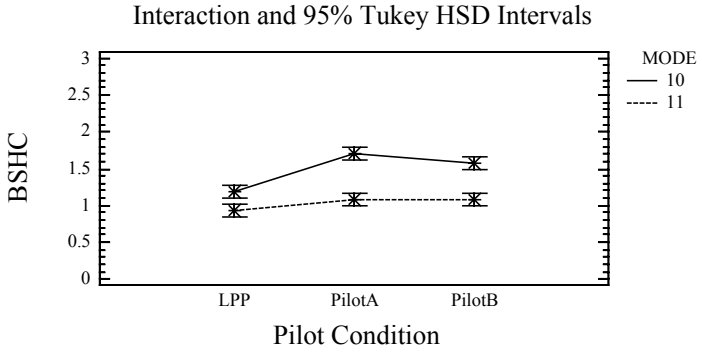
MODE	Count	LS Mean	Homogeneous Groups
11	45	1.03446	X
10	46	1.4866	X

Contrast	Difference	+/- Limits
10 - 11	*0.452133	0.0633075

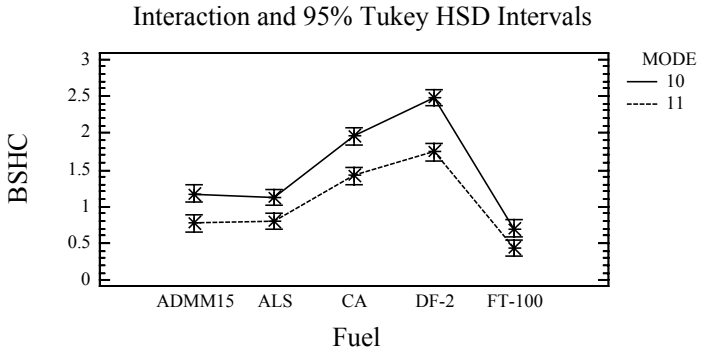
* denotes a statistically significant difference.



CONCLUSION: The CA and DF-2 fuels have significantly different trends in the average BSHC at the Pilot B condition than at the other two pilot conditions.



CONCLUSION: Mode 11 demonstrates a constant trend with respect to the average BSHC. However, mode 10 shows significantly different average BSHC at Pilot Conditions A and B than at the LPP condition.

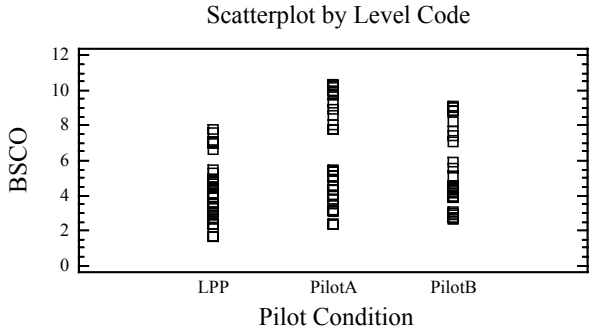


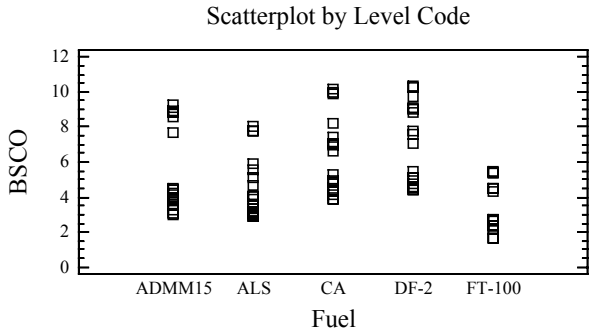
CONCLUSION: A significant interaction exists between the mode and fuel levels. The differences in the average BSHC between modes 10 and 11 are largest at the CA and DF-2 fuels and the smallest at the FT-100 fuel.

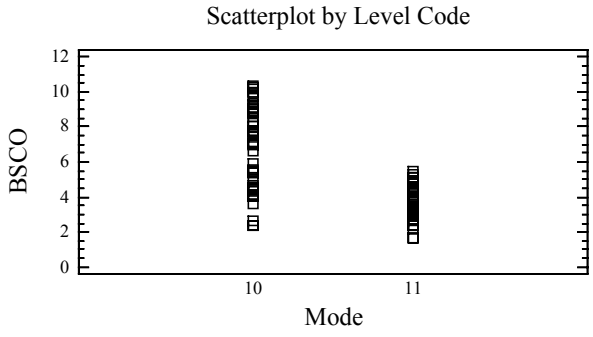
Multifactor ANOVA - BSCO (g/kW-hr)
Three Pilot Conditions Modes 10 and 11
Analysis Summary

Dependent variable: BSCO
Factors:
COND
FUEL
MODE

Number of complete cases: 91







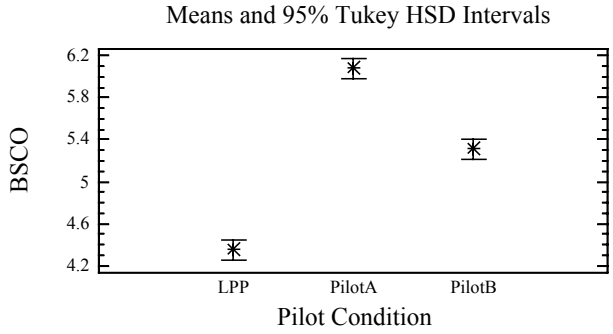
Analysis of Variance for BSCO - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	45.521	2	22.7605	256.44	0.0000
B:FUEL	150.552	4	37.6379	424.05	0.0000
C:MODE	229.06	1	229.06	2580.74	0.0000
INTERACTIONS					

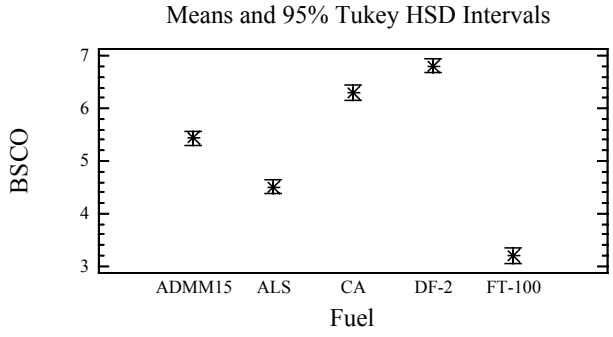
AB	13.742	8	1.71774	19.35	0.0000
AC	43.4943	2	21.7471	245.02	0.0000
BC	15.4364	4	3.85911	43.48	0.0000
ABC	3.21386	8	0.401733	4.53	0.0002
RESIDUAL	5.4142	61	0.0887574		
TOTAL (CORRECTED)	504.085	90			

All F-ratios are based on the residual mean square error.

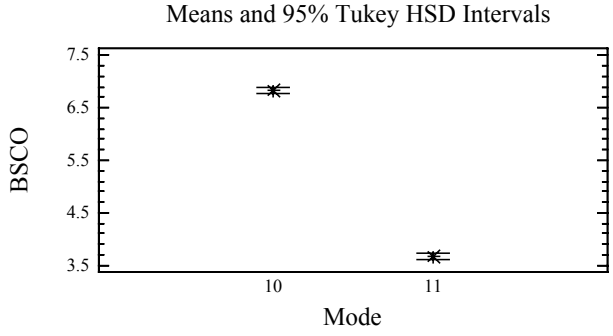
CONCLUSION: Statistically significant differences in the average BSCO among the fuels, pilot conditions, modes, two-way interactions, and three-way interaction.



CONCLUSION: All three pilot conditions are significantly different from one another with respect to the average BSCO.



CONCLUSION: All five fuels are significantly different from one another with respect to the average BSCO.



CONCLUSION: Modes 10 and 11 are significantly different from one another with respect to the average BSCO.

Multiple Range Tests for BSCO by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	4.3539	X
PilotB	30	5.3134	X
PilotA	30	6.08064	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-1.72674	0.183303
LPP - PilotB	*-0.959501	0.183303
PilotA - PilotB	*0.767243	0.1848

* denotes a statistically significant difference.

Multiple Range Tests for BSCO by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	3.19551	X
ALS	19	4.50613	X
ADMM15	18	5.43576	X
CA	18	6.30206	X
DF-2	18	6.8071	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*0.929626	0.275463
ADMM15 - CA	*-0.8663	0.279161
ADMM15 - DF-2	*-1.37134	0.279161
ADMM15 - FT-100	*2.24025	0.279161
ALS - CA	*-1.79593	0.275463
ALS - DF-2	*-2.30097	0.275463
ALS - FT-100	*1.31063	0.275463
CA - DF-2	*-0.505044	0.279161
CA - FT-100	*3.10655	0.279161
DF-2 - FT-100	*3.6116	0.279161

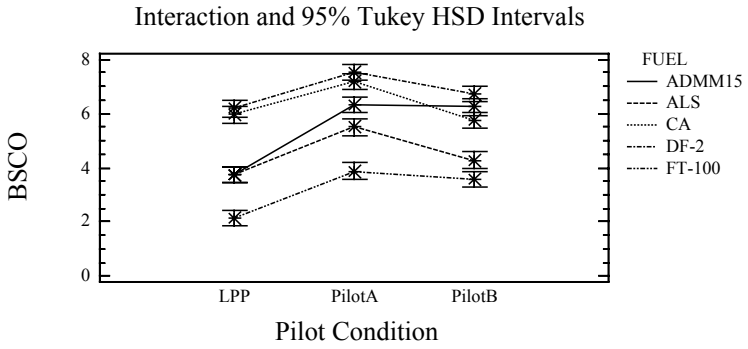
* denotes a statistically significant difference.

Multiple Range Tests for BSCO by MODE

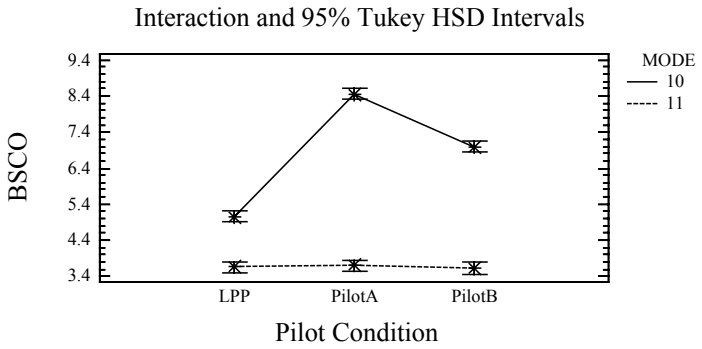
Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
11	45	3.66063	X
10	46	6.83799	X

Contrast	Difference	+/- Limits
10 - 11	*3.17736	0.124907

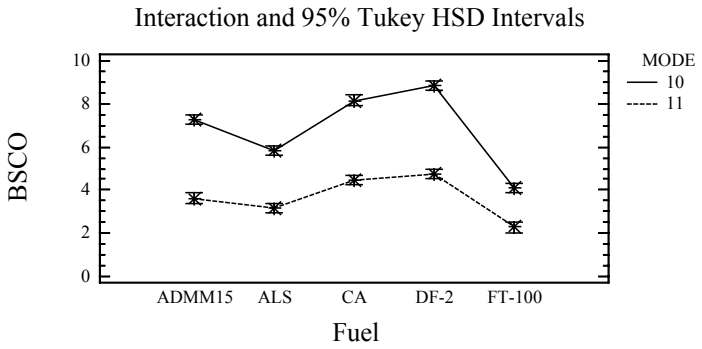
* denotes a statistically significant difference.



CONCLUSION: The trend in the average BSCO for the ADMM15 fuel is significantly different across the pilot conditions than the trends for the remaining four fuels.



CONCLUSION: Mode 11 demonstrates a constant trend with respect to the average BSCO. However, mode 10 shows significantly different average BSCO at all three pilot conditions.



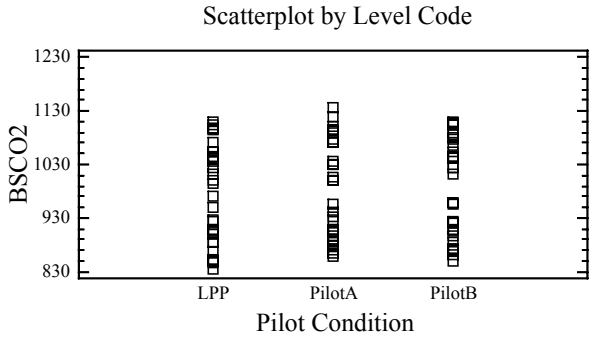
CONCLUSION: A significant interaction exists between the mode and fuel levels. The difference in the average BSCO between modes 10 and 11 is the largest at fuels CA and DF-2 and the smallest at the FT-100 fuel.

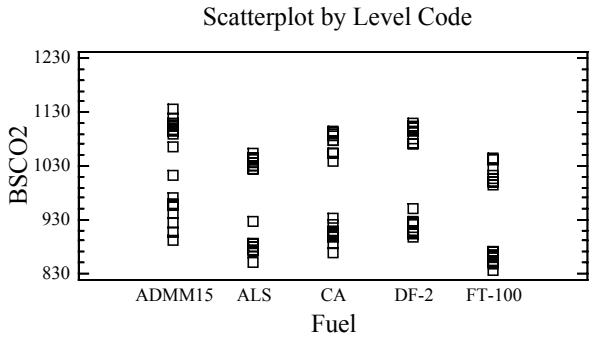
Multifactor ANOVA - BSCO2 (g/kW-hr)
Three Pilot Conditions Modes 10 and 11

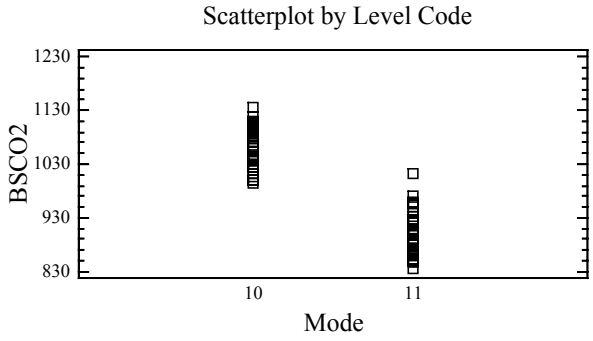
Analysis Summary

Dependent variable: BSCO2
Factors:
COND
FUEL
MODE

Number of complete cases: 91







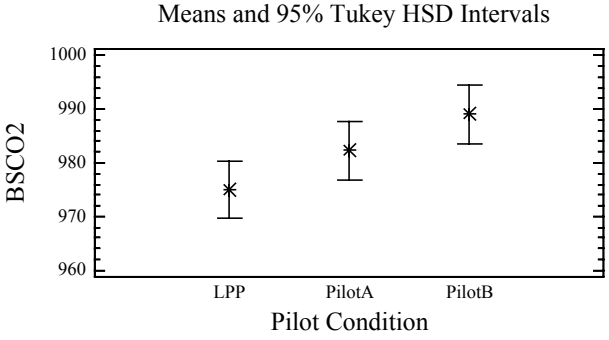
Analysis of Variance for BSCO2 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	3026.88	2	1513.44	4.93	0.0103
B:FUEL	90449.4	4	22612.3	73.73	0.0000
C:MODE	601921.0	1	601921.0	1962.53	0.0000

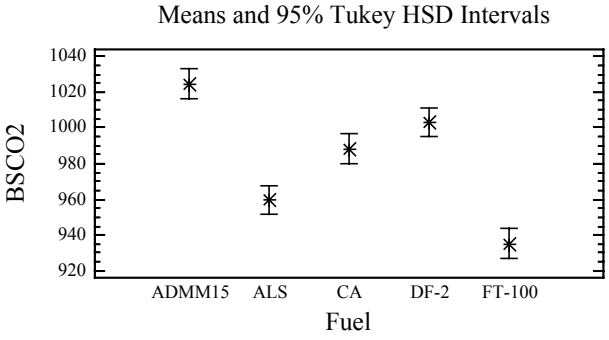
INTERACTIONS					
AB	4505.4	8	563.175	1.84	0.0874
AC	24.0168	2	12.0084	0.04	0.9616
BC	1529.07	4	382.267	1.25	0.3009
ABC	5306.95	8	663.369	2.16	0.0430
RESIDUAL	18709.1	61	306.707		
TOTAL (CORRECTED)	722927.0	90			

All F-ratios are based on the residual mean square error.

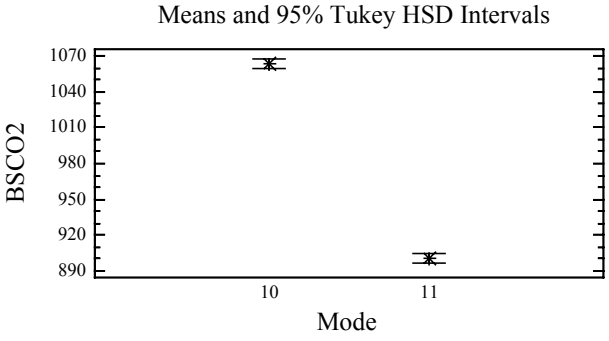
CONCLUSION: Statistically significant differences in the average BSCO2 among the fuels, modes, pilot conditions, and three-way interaction.



CONCLUSION: The average BSCO2 for the Pilot B condition is significantly different than the LPP condition.



CONCLUSION: The average BSCO2 for the FT-100, ALS, and ADMM15 fuels are significantly different from each other and the remaining two fuels. The average BSCO2 for the CA and DF-2 fuels are not significantly different from one another.



CONCLUSION: Modes 10 and 11 are significantly different from one another with respect to the average BSCO2.

Multiple Range Tests for BSCO2 by COND

Method: 95.0 percent Tukey HSD

COND	Count	LS Mean	Homogeneous Groups
LPP	31	974.954	X
PilotA	30	982.223	XX
PilotB	30	989.066	X

Contrast	Difference	+/- Limits
LPP - PilotA	-7.26834	10.7753
LPP - PilotB	*-14.112	10.7753
PilotA - PilotB	-6.84368	10.8633

* denotes a statistically significant difference.

Multiple Range Tests for BSCO2 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	935.124	X
ALS	19	959.404	X
CA	18	988.251	X
DF-2	18	1003.05	X
ADMM15	18	1024.58	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*65.1737	16.1928
ADMM15 - CA	*36.3268	16.4102
ADMM15 - DF-2	*21.5309	16.4102
ADMM15 - FT-100	*89.4536	16.4102
ALS - CA	*-28.8469	16.1928
ALS - DF-2	*-43.6428	16.1928
ALS - FT-100	*24.2799	16.1928
CA - DF-2	-14.7959	16.4102
CA - FT-100	*53.1268	16.4102
DF-2 - FT-100	*67.9228	16.4102

* denotes a statistically significant difference.

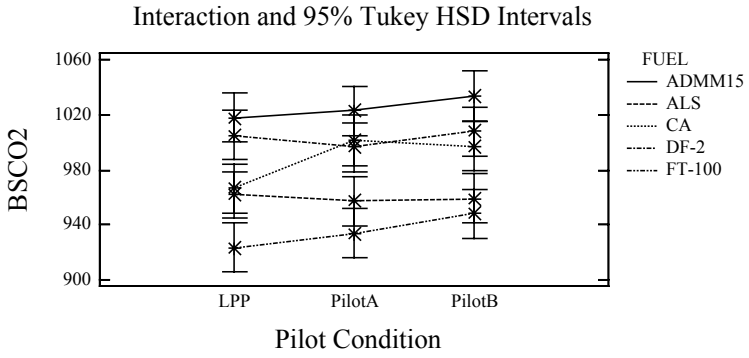
Multiple Range Tests for BSCO2 by MODE

Method: 95.0 percent Tukey HSD

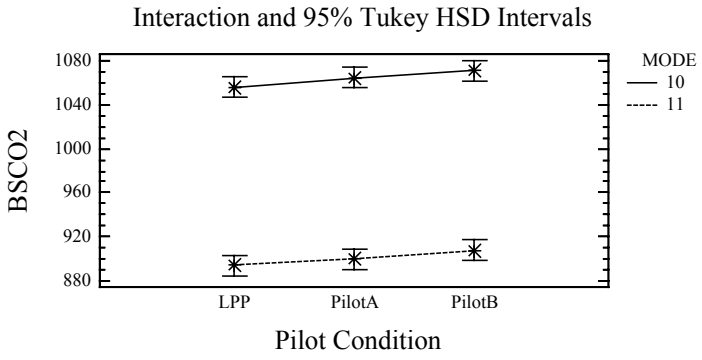
MODE	Count	LS Mean	Homogeneous Groups
11	45	900.642	X
10	46	1063.52	X

Contrast	Difference	+/- Limits
10 - 11	*162.878	7.34254

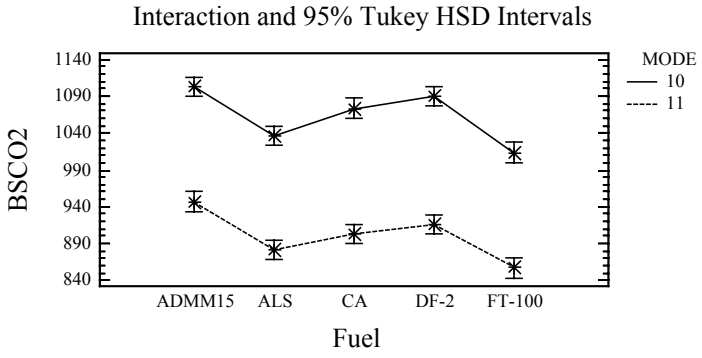
* denotes a statistically significant difference.



CONCLUSION: No significant differences among the fuel and pilot condition combinations with respect to the average BSCO2.



CONCLUSION: No significant differences among the mode and pilot condition combinations with respect to the average BSCO2.



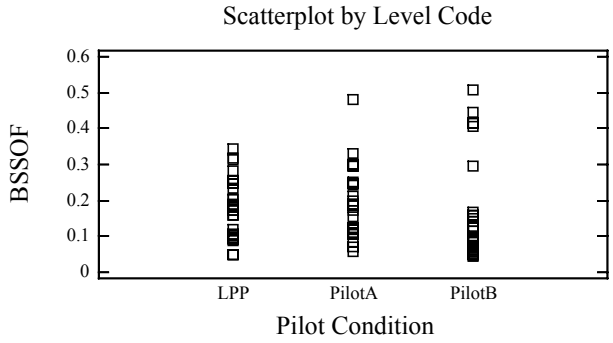
CONCLUSION: No significant differences among the mode and fuel combinations with respect to the average BSCO2.

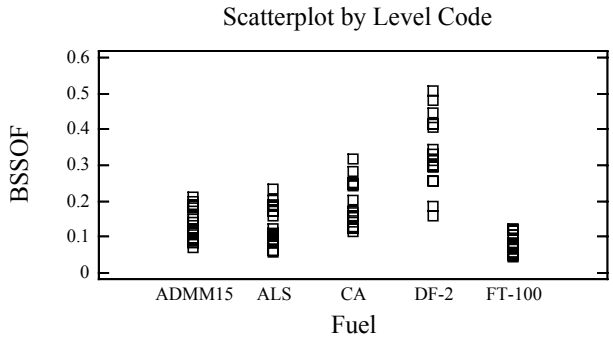
Multifactor ANOVA - BSSOF (g/kW-hr)
Three Pilot Conditions Modes 10 and 11

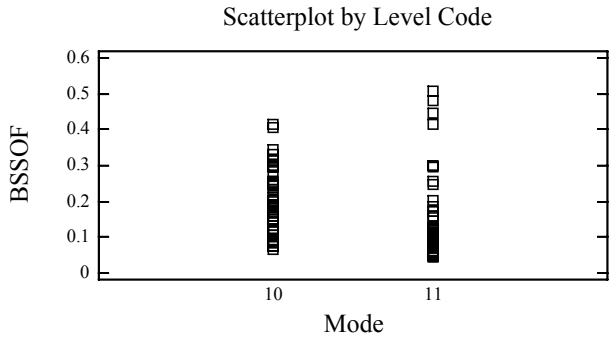
Analysis Summary

Dependent variable: bssof
Factors:
COND
FUEL
MODE

Number of complete cases: 90







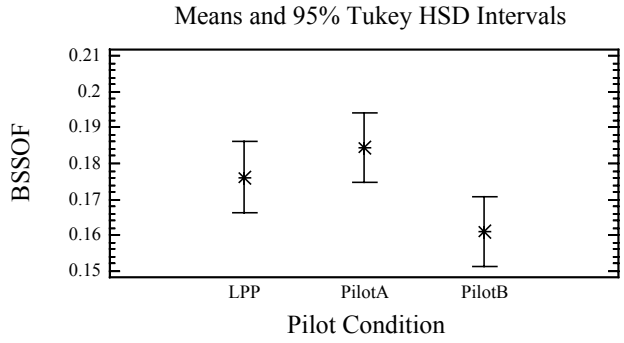
Analysis of Variance for bssof - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	0.00848506	2	0.00424253	4.23	0.0191

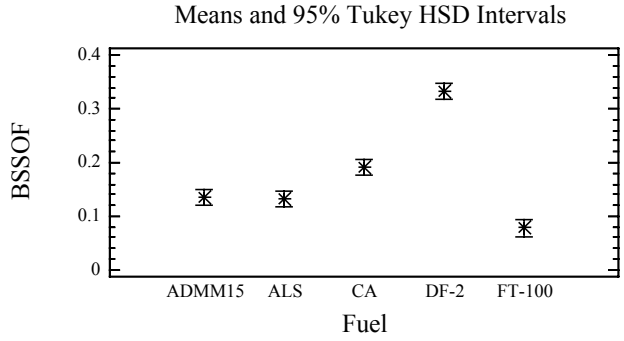
B:FUEL	0.677894	4	0.169473	169.05	0.0000
C:MODE	0.0493254	1	0.0493254	49.20	0.0000
INTERACTIONS					
AB	0.141082	8	0.0176353	17.59	0.0000
AC	0.0174835	2	0.00874174	8.72	0.0005
BC	0.0224319	4	0.00560796	5.59	0.0007
ABC	0.0221993	8	0.00277492	2.77	0.0113
RESIDUAL	0.0601491	60	0.00100248		
TOTAL (CORRECTED)	0.994981	89			

All F-ratios are based on the residual mean square error.

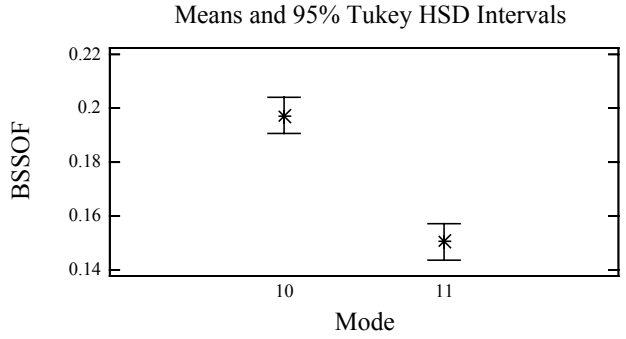
CONCLUSION: Statistically significant differences in the average BSSOF among the fuels, modes, pilot conditions, all two-factor interactions, and the three-factor interaction between the fuel*mode*pilot condition.



CONCLUSION: The average BSSOF for the Pilot A condition is significantly different from the Pilot B condition.



CONCLUSION: The average BSSOF for the FT-100, CA, and DF-2 fuels are significantly different from one another and the remaining two fuels. The average BSSOF for the ADMM15 and ALS fuels are not significantly different from one another.



CONCLUSION: The average BSSOF for modes 10 and 11 are statistically significant from one another.

Multiple Range Tests for bssof by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
PilotB	30	0.160938	X
LPP	30	0.176213	XX
PilotA	30	0.18437	X

Contrast	Difference	+/- Limits
LPP - PilotA	-0.00815713	0.019648
LPP - PilotB	0.0152749	0.019648
PilotA - PilotB	*0.023432	0.019648

* denotes a statistically significant difference.

Multiple Range Tests for bssof by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	17	0.0776545	X
ALS	19	0.132759	X
ADMM15	18	0.133725	X
CA	18	0.191733	X
DF-2	18	0.333329	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	0.000965815	0.0292901
ADMM15 - CA	*-0.0580086	0.0296832
ADMM15 - DF-2	*-0.199604	0.0296832
ADMM15 - FT-100	*0.0560701	0.0301166
ALS - CA	*-0.0589745	0.0292901
ALS - DF-2	*-0.20057	0.0292901
ALS - FT-100	*0.0551043	0.0297292
CA - DF-2	*-0.141596	0.0296832
CA - FT-100	*0.114079	0.0301166
DF-2 - FT-100	*0.255674	0.0301166

* denotes a statistically significant difference.

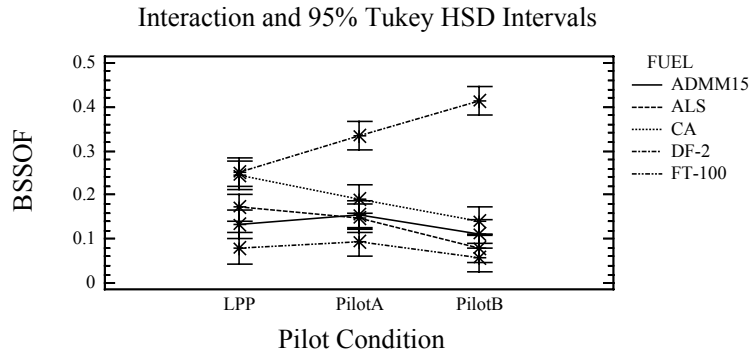
Multiple Range Tests for bssof by MODE

Method: 95.0 percent Tukey HSD

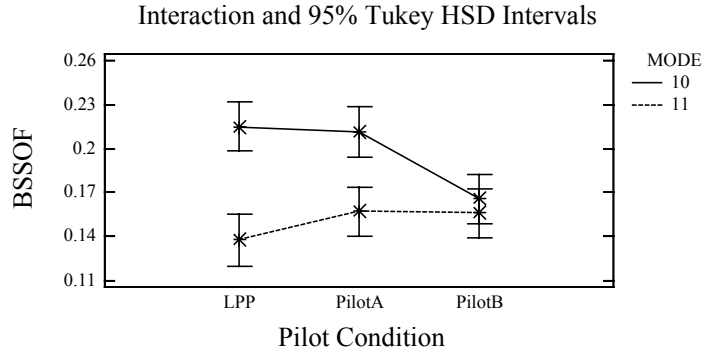
MODE	Count	LS Mean	Homogeneous Groups
11	44	0.150332	X
10	46	0.197348	X

Contrast	Difference	+/- Limits
10 - 11	*0.0470161	0.0133552

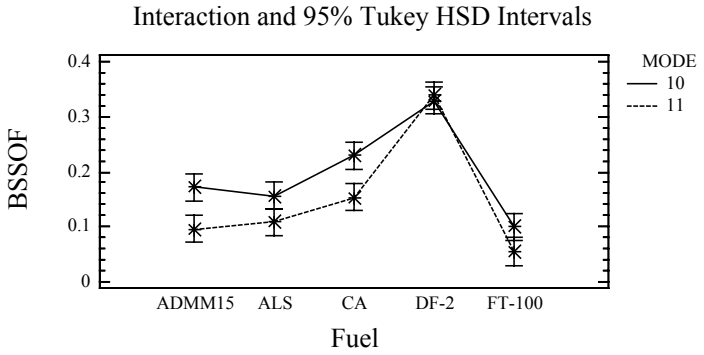
* denotes a statistically significant difference.



CONCLUSION: The trend in the average BSSOF across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average BSSOF for the DF-2 fuel at the Pilot A and Pilot B conditions are significantly different than the other four fuels.



CONCLUSION: The average BSSOF at the LPP and Pilot A conditions for Mode 10 are significantly different than those at Mode 11. There is not a significant difference in the average BSSOF between the two modes at the Pilot B condition.



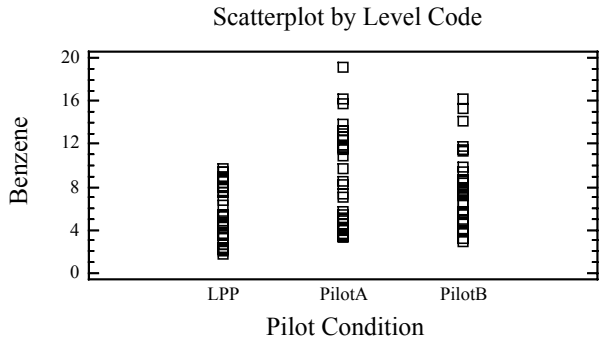
CONCLUSION: The trends in the average BSSOF across the two modes are different at fuels ADMM15 and CA. There does not appear to be differences in the average BSSOF for the two modes at the ALS, DF-2 or FT-100 fuels.

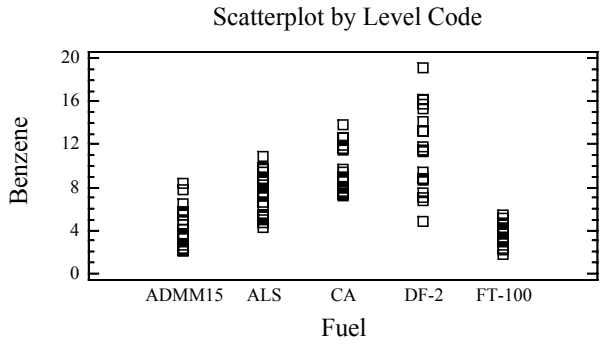
Multifactor ANOVA - BENZENE (mg/kW-hr) Toxic Gaseous Emissions
Three Pilot Conditions Modes 10 and 11

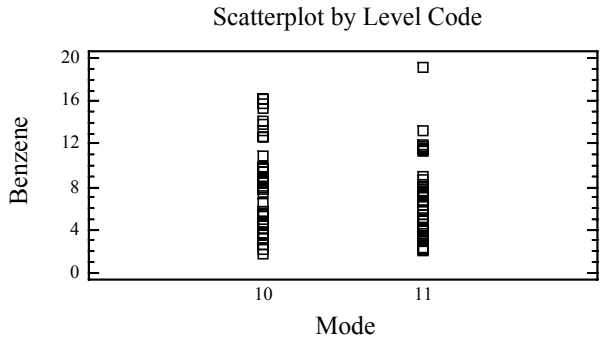
Analysis Summary

Dependent variable: BENZENE
Factors:
COND
FUEL
MODE

Number of complete cases: 91







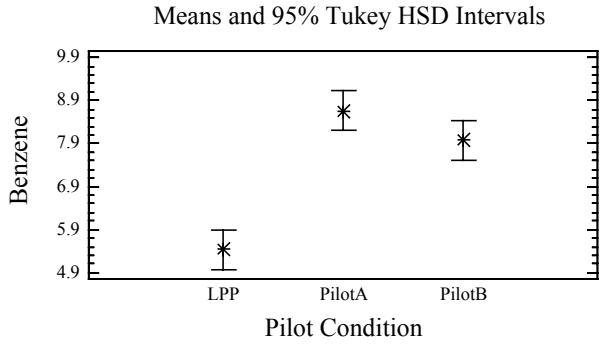
Analysis of Variance for BENZENE - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	176.208	2	88.1042	40.24	0.0000
B:FUEL	843.208	4	210.802	96.27	0.0000

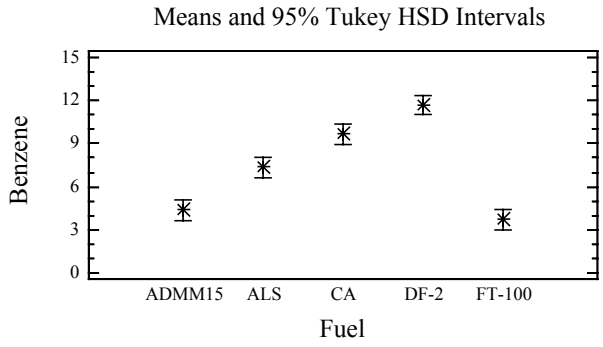
C:MODE	45.7314	1	45.7314	20.89	0.0000
INTERACTIONS					
AB	123.013	8	15.3766	7.02	0.0000
AC	4.81639	2	2.40819	1.10	0.3394
BC	10.8557	4	2.71392	1.24	0.3037
ABC	4.53938	8	0.567422	0.26	0.9765
RESIDUAL	133.569	61	2.18966		
TOTAL (CORRECTED)	1339.93	90			

All F-ratios are based on the residual mean square error.

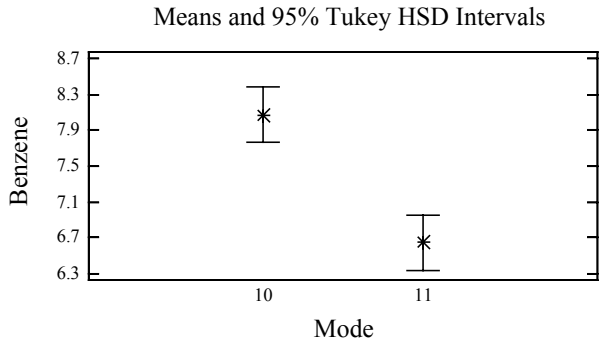
CONCLUSION: Statistically significant differences in the average benzene among the fuels, modes, pilot conditions, and the fuel*pilot condition interaction.



CONCLUSION: The average benzene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP conditions.



CONCLUSION: The average benzene for the ALS, CA, and DF-2 fuels are significantly different from one another and the remaining two fuels. The average benzene for the ADMM15 and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average benzene for modes 10 and 11 are significantly different from one another.

Multiple Range Tests for BENZENE by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	5.43508	X
PilotB	30	7.97672	X
PilotA	30	8.66153	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-3.22645	0.91045
LPP - PilotB	*-2.54164	0.91045
PilotA - PilotB	0.684804	0.917883

* denotes a statistically significant difference.

Multiple Range Tests for BENZENE by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	3.70071	X
ADMM15	18	4.35116	X
ALS	19	7.34001	X
CA	18	9.6714	X
DF-2	18	11.7256	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-2.98885	1.3682
ADMM15 - CA	*-5.32024	1.38657
ADMM15 - DF-2	*-7.37443	1.38657
ADMM15 - FT-100	0.65045	1.38657
ALS - CA	*-2.33139	1.3682
ALS - DF-2	*-4.38558	1.3682
ALS - FT-100	*3.6393	1.3682
CA - DF-2	*-2.05419	1.38657
CA - FT-100	*5.97069	1.38657
DF-2 - FT-100	*8.02488	1.38657

* denotes a statistically significant difference.

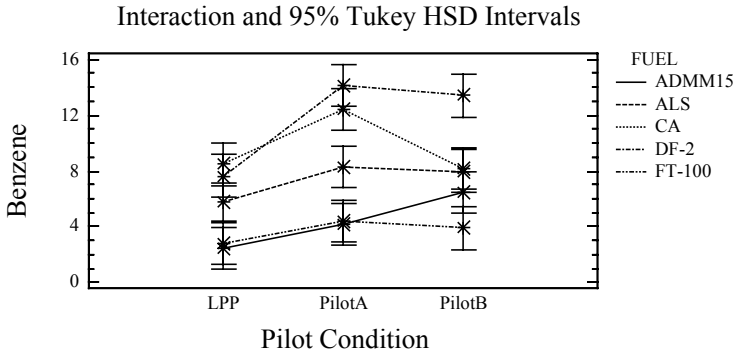
Multiple Range Tests for BENZENE by MODE

Method: 95.0 percent Tukey HSD

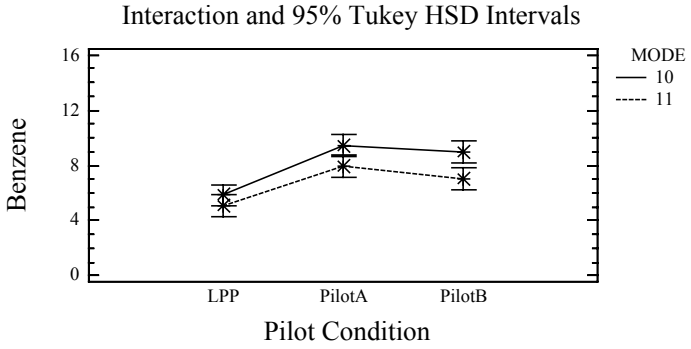
MODE	Count	LS Mean	Homogeneous Groups
11	45	6.64792	X
10	46	8.06763	X

Contrast	Difference	+/- Limits
10 - 11	*1.41971	0.620402

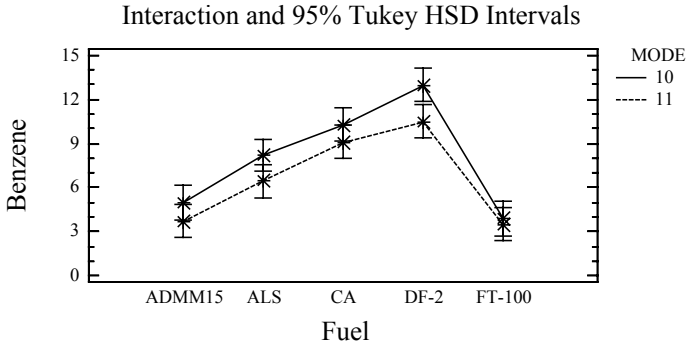
* denotes a statistically significant difference.



CONCLUSION: The trend in the average benzene across the pilot conditions for the DF-2 and CA fuels is significantly different than the trends for the remaining three fuels. The average benzene for the DF-2 fuel at the Pilot B condition is significantly different than the other four fuels, but not at the LPP condition. Also, the Pilot A condition demonstrates that the average benzene for the DF-2 and CA fuels are not significantly different from one another.



CONCLUSION: There is no significant interaction in the average benzene among the mode and pilot condition combinations.



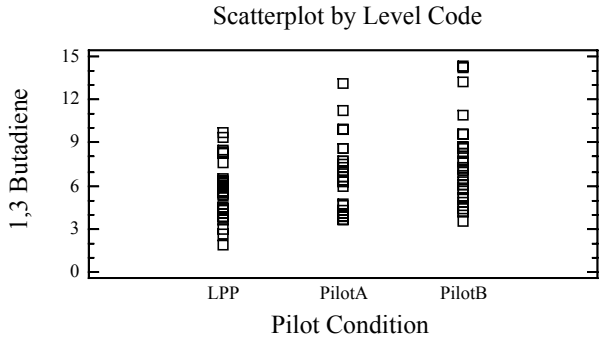
CONCLUSION: There is no significant interaction in the average benzene among the mode and fuel combinations.

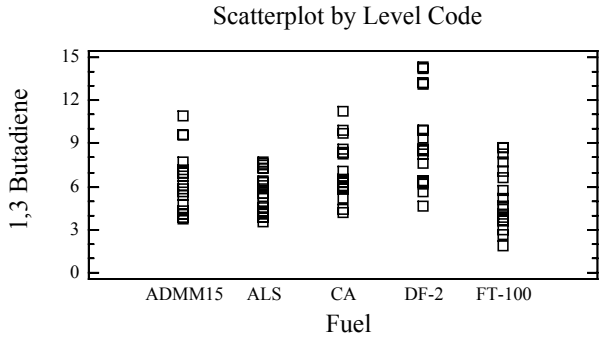
Multifactor ANOVA - 1,3 Butadiene (mg/kW-hr) Toxic Gaseous Emissions
Three Pilot Conditions Modes 10 and 11

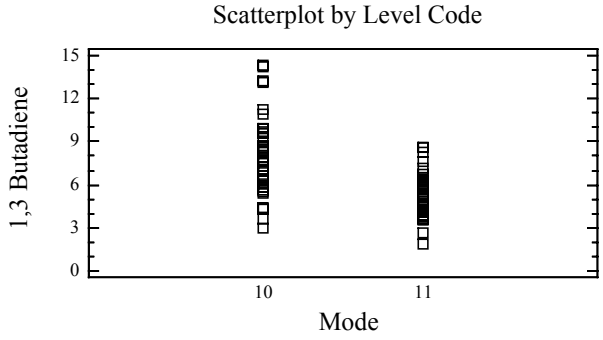
Analysis Summary

Dependent variable: BUTAD
Factors:
COND
FUEL
MODE

Number of complete cases: 91







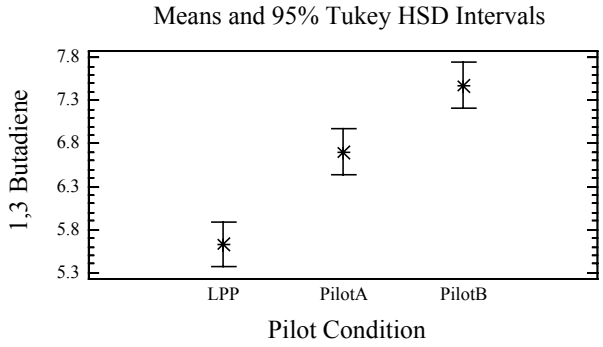
Analysis of Variance for BUTAD - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	52.2836	2	26.1418	35.11	0.0000
B:FUEL	163.144	4	40.7859	54.78	0.0000

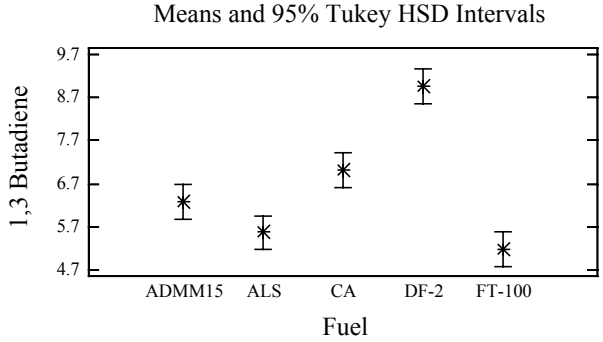
C:MODE	183.857	1	183.857	246.94	0.0000
INTERACTIONS					
AB	100.982	8	12.6227	16.95	0.0000
AC	19.6903	2	9.84514	13.22	0.0000
BC	9.36558	4	2.3414	3.14	0.0204
ABC	9.57871	8	1.19734	1.61	0.1412
RESIDUAL	45.4168	61	0.744538		
TOTAL (CORRECTED)	580.649	90			

All F-ratios are based on the residual mean square error.

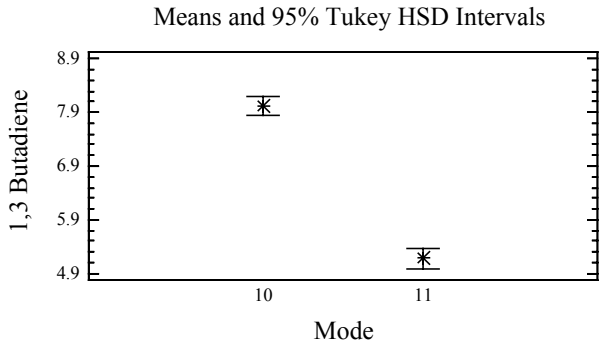
CONCLUSION: Statistically significant differences in the average 1,3 butadiene among the fuels, modes, pilot conditions, and two-way interactions.



CONCLUSION: All three pilot conditions are significantly different from one another with respect to the average 1,3 butadiene.



CONCLUSION: There are several distinct fuel groupings with respect to the average 1,3 butadiene. The average 1,3 butadiene for the DF-2 fuel is significantly different than the remaining four fuels. The FT-100 fuel is significantly different than the ADMM15 and CA fuels, but not significantly different than the ALS fuel. Also, the average
1,3 butadiene for the CA fuel is significantly different than the ALS fuel.



CONCLUSION: The average 1,3 butadiene for mode 10 is significantly different than mode 11.

Multiple Range Tests for BUTAD by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	5.62805	X
PilotA	30	6.70067	X
PilotB	30	7.47402	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-1.07262	0.530898
LPP - PilotB	*-1.84597	0.530898
PilotA - PilotB	*-0.773342	0.535232

* denotes a statistically significant difference.

Multiple Range Tests for BUTAD by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	5.17097	X
ALS	19	5.56048	XX
ADMM15	18	6.29433	XX
CA	18	7.00454	X
DF-2	18	8.97425	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	0.733847	0.79782
ADMM15 - CA	-0.710209	0.80853
ADMM15 - DF-2	*-2.67992	0.80853
ADMM15 - FT-100	*1.12336	0.80853
ALS - CA	*-1.44406	0.79782
ALS - DF-2	*-3.41377	0.79782
ALS - FT-100	0.389514	0.79782
CA - DF-2	*-1.96971	0.80853
CA - FT-100	*1.83357	0.80853
DF-2 - FT-100	*3.80328	0.80853

* denotes a statistically significant difference.

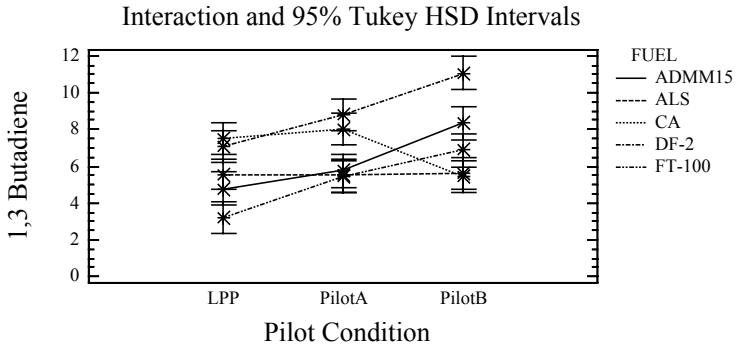
Multiple Range Tests for BUTAD by MODE

Method: 95.0 percent Tukey HSD

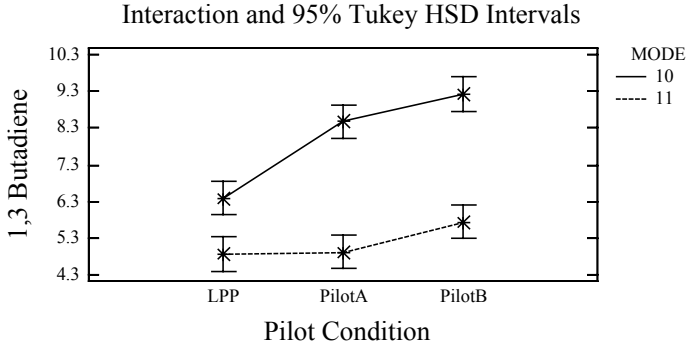
MODE	Count	LS Mean	Homogeneous Groups
11	45	5.17759	X
10	46	8.02423	X

Contrast	Difference	+/- Limits
10 - 11	*2.84664	0.361766

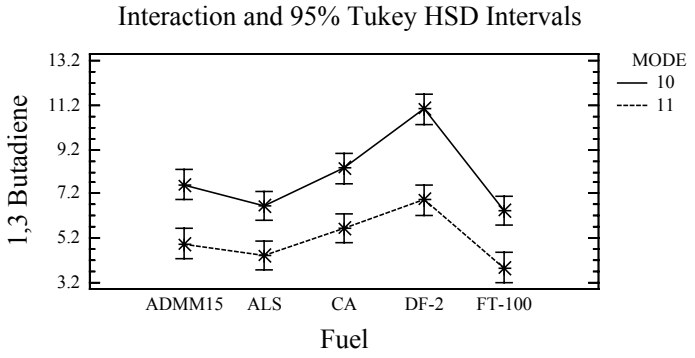
* denotes a statistically significant difference.



CONCLUSION: The trends in the average 1,3 butadiene across the pilot conditions for the DF-2 and FT-100 fuels appear similar. However, the ALS fuel demonstrates an almost constant average 1,3 butadiene across all three pilot conditions while the CA fuel shows a significant decrease from the Pilot A to Pilot B conditions.



CONCLUSION: A significant interaction exists between the pilot condition and the modes. The difference in the average 1,3 butadiene between the two modes at the LPP condition is smaller than the differences at the Pilot A and Pilot B conditions.

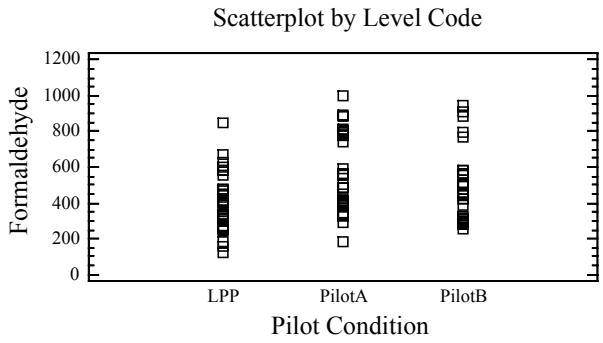


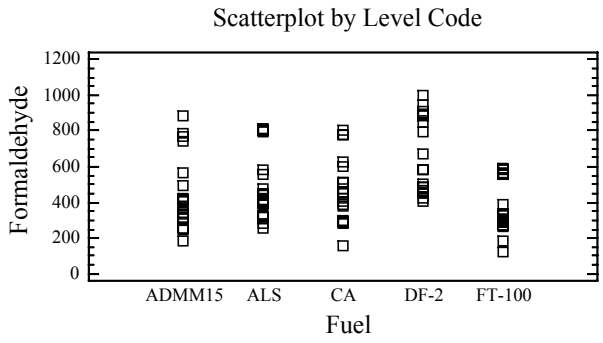
CONCLUSION: A significant interaction exists between the mode and the fuel levels. The difference in the average 1,3 butadiene between modes 10 and 11 is the largest at the DF-2 fuel and the smallest at the ALS fuel.

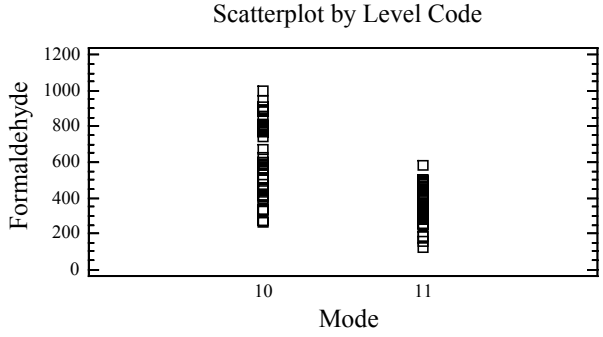
Multifactor ANOVA - Formaldehyde (mg/W-hr) Toxic Gaseous Emissions
Three Pilot Conditions Modes 10 and 11
Analysis Summary

Dependent variable: FORMALD
Factors:
COND
FUEL
MODE

Number of complete cases: 91







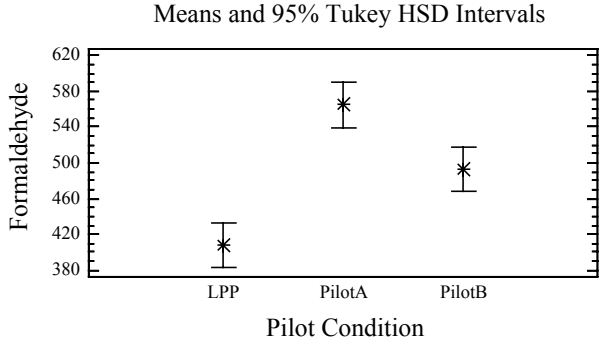
Analysis of Variance for FORMALD - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	372467.0	2	186234.0	28.61	0.0000
B:FUEL	740668.0	4	185167.0	28.44	0.0000
C:MODE	1.54489E6	1	1.54489E6	237.29	0.0000

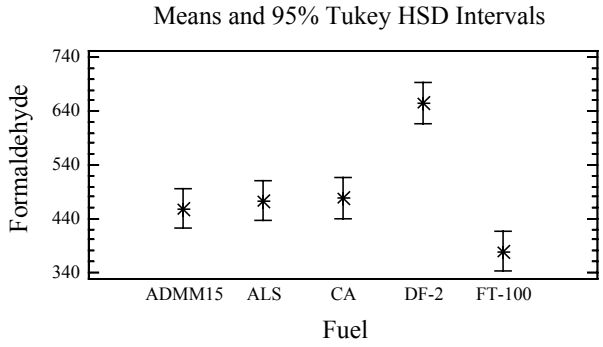
INTERACTIONS					
AB	307919.0	8	38489.8	5.91	0.0000
AC	199851.0	2	99925.7	15.35	0.0000
BC	76005.8	4	19001.5	2.92	0.0283
ABC	55295.1	8	6911.89	1.06	0.4016
RESIDUAL	397136.0	61	6510.43		
TOTAL (CORRECTED)	3.67275E6	90			

All F-ratios are based on the residual mean square error.

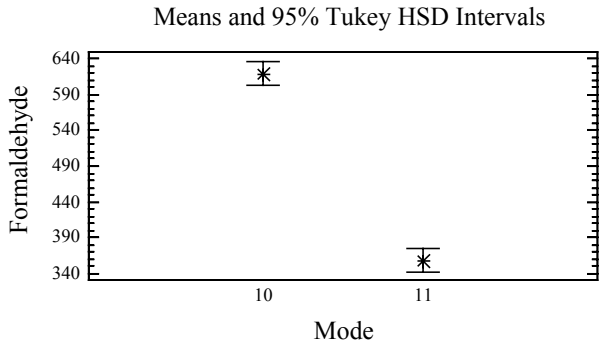
CONCLUSION: Statistically significant differences in the average formaldehyde among the fuels, modes, pilot conditions, and two-way interactions.



CONCLUSION: All three pilot conditions are significantly different from one another with respect to the average formaldehyde.



CONCLUSION: There are three distinct fuel groupings with respect to the average formaldehyde. Fuels FT-100 and DF-2 are significantly different from one another and the remaining three fuels. The ADMM15, ALS, and CA fuels are not significantly different from one another, but are significantly different than the other two fuels.



CONCLUSION: The average formaldehyde for mode 10 is significantly different than mode 11.

Multiple Range Tests for FORMALD by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	408.327	X
PilotB	30	493.116	X
PilotA	30	564.674	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-156.347	49.6447
LPP - PilotB	*-84.7886	49.6447
PilotA - PilotB	*71.5582	50.0499

* denotes a statistically significant difference.

Multiple Range Tests for FORMALD by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	378.998	X
ADMM15	18	458.316	X
ALS	19	472.468	X
CA	18	478.293	X
DF-2	18	655.455	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-14.1521	74.6048
ADMM15 - CA	-19.9768	75.6062
ADMM15 - DF-2	*-197.139	75.6062
ADMM15 - FT-100	*79.3182	75.6062
ALS - CA	-5.82469	74.6048
ALS - DF-2	*-182.987	74.6048
ALS - FT-100	*93.4703	74.6048
CA - DF-2	*-177.163	75.6062
CA - FT-100	*99.295	75.6062
DF-2 - FT-100	*276.458	75.6062

* denotes a statistically significant difference.

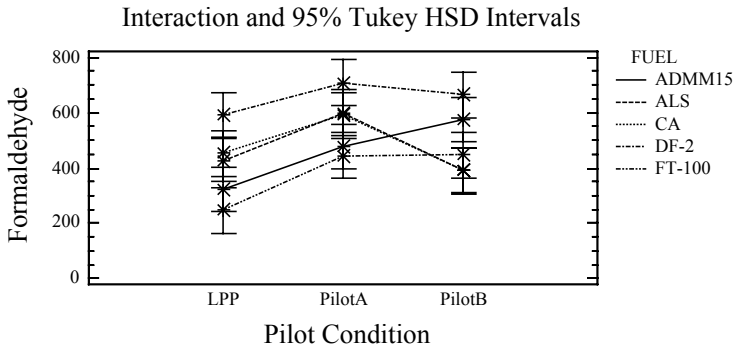
Multiple Range Tests for FORMALD by MODE

Method: 95.0 percent Tukey HSD

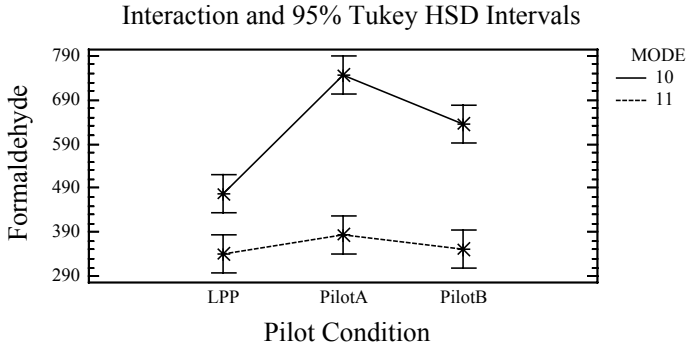
MODE	Count	LS Mean	Homogeneous Groups
11	45	358.236	X
10	46	619.175	X

Contrast	Difference	+/- Limits
10 - 11	*260.939	33.829

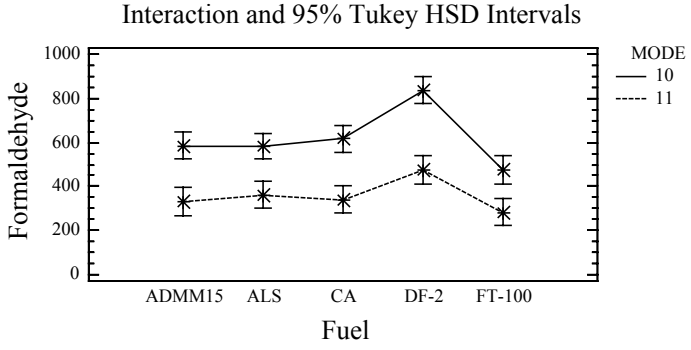
* denotes a statistically significant difference.



CONCLUSION: The trends in the average formaldehyde across the pilot conditions for the CA and ALS fuels appear similar. However, the ADMM15 fuel demonstrates an increase in the average formaldehyde from the Pilot A to the Pilot B conditions, whereas the CA and ALS fuels showed a decrease.



CONCLUSION: A significant interaction exists between the pilot conditions and the modes. The difference in the average formaldehyde between the two modes at the LPP condition is smaller than the differences at the Pilot A and Pilot B conditions.



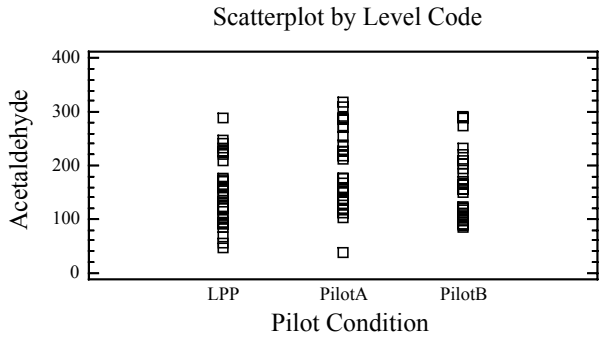
CONCLUSION: A significant interaction exists between the mode and the fuel levels. The difference in the average formaldehyde between modes 10 and 11 is the largest at the DF-2 fuel and the smallest at the ALS fuel.

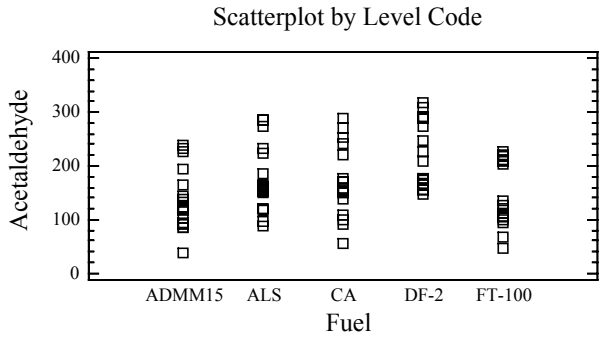
Multifactor ANOVA - Acetaldehyde (mg/kW-hr) Toxic Gaseous Emissions
Three Pilot Conditions Modes 10 and 11

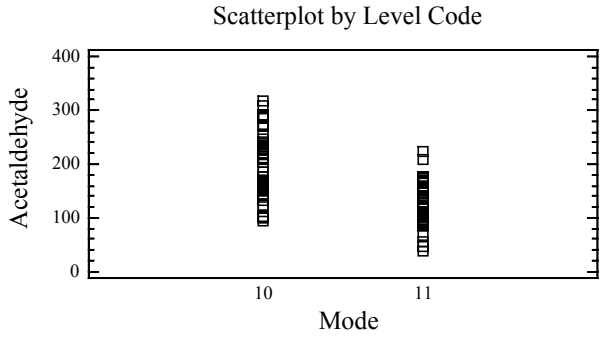
Analysis Summary

Dependent variable: ACETALD
Factors:
COND
FUEL
MODE

Number of complete cases: 91







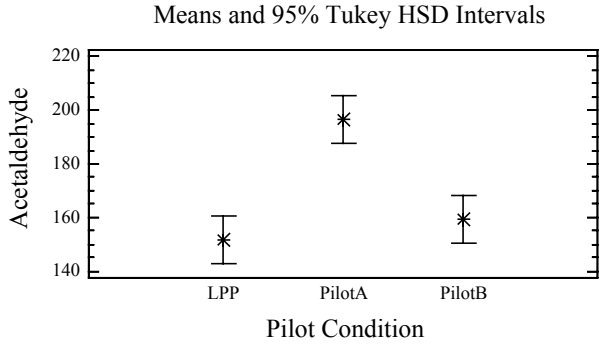
Analysis of Variance for ACETALD - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	34346.8	2	17173.4	20.91	0.0000
B:FUEL	92632.3	4	23158.1	28.20	0.0000
C:MODE	159403.0	1	159403.0	194.11	0.0000

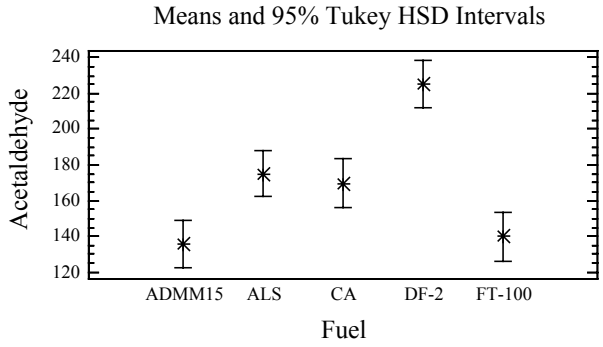
INTERACTIONS					
AB	37491.4	8	4686.43	5.71	0.0000
AC	16558.1	2	8279.06	10.08	0.0002
BC	5617.49	4	1404.37	1.71	0.1593
ABC	7258.13	8	907.266	1.10	0.3727
RESIDUAL	50093.8	61	821.209		
TOTAL (CORRECTED)	401292.0	90			

All F-ratios are based on the residual mean square error.

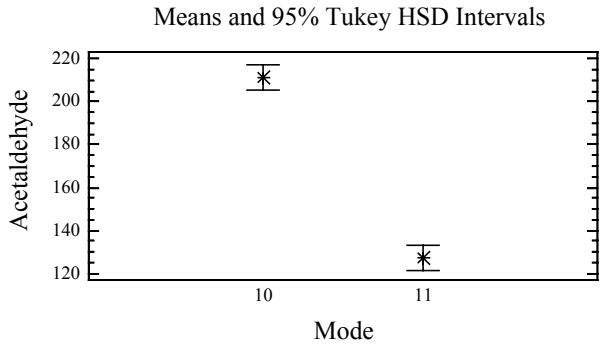
CONCLUSION: Statistically significant differences in the average acetaldehyde among the fuels, modes, pilot conditions, and some two-way interactions.



CONCLUSION: The average acetaldehyde for the LPP and Pilot B conditions are not significantly different from one another, but are different from the Pilot A condition.



CONCLUSION: There are three distinct fuel groupings with respect to the average acetaldehyde. The DF-2 fuel is significantly different from the remaining four fuels. The ADMM15 and FT-100 fuels are not significantly different from one another, but are different from the other fuels. Also, the CA and ALS fuels are not significantly different from one another, but are different from the other fuels.



CONCLUSION: The average acetaldehyde for mode 10 is significantly different than mode 11.

Multiple Range Tests for ACETALD by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	151.651	X
PilotB	30	159.56	X
PilotA	30	196.333	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-44.6817	17.6317
LPP - PilotB	-7.9089	17.6317
PilotA - PilotB	*36.7728	17.7757

* denotes a statistically significant difference.

Multiple Range Tests for ACETALD by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	135.992	X
FT-100	18	139.76	X
CA	18	169.815	X
ALS	19	175.105	X
DF-2	18	225.236	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-39.1129	26.4965
ADMM15 - CA	*-33.8224	26.8522
ADMM15 - DF-2	*-89.2434	26.8522
ADMM15 - FT-100	-3.76753	26.8522
ALS - CA	5.29049	26.4965
ALS - DF-2	*-50.1305	26.4965
ALS - FT-100	*35.3454	26.4965
CA - DF-2	*-55.421	26.8522
CA - FT-100	*30.0549	26.8522
DF-2 - FT-100	*85.4759	26.8522

* denotes a statistically significant difference.

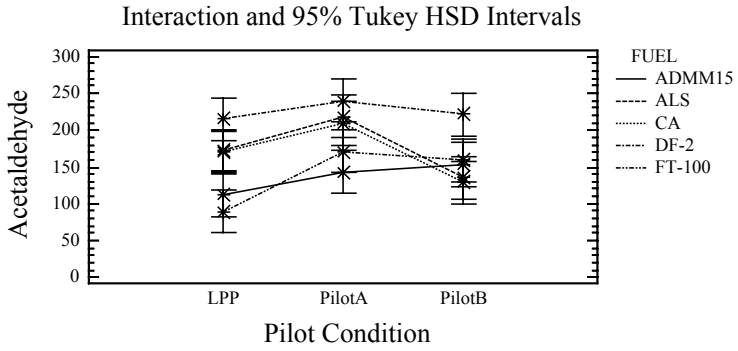
Multiple Range Tests for ACETALD by MODE

Method: 95.0 percent Tukey HSD

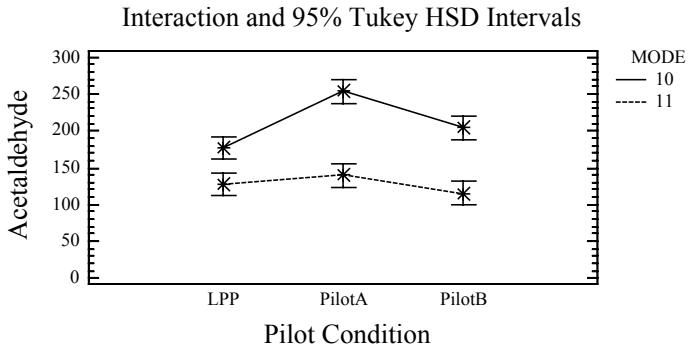
MODE	Count	LS Mean	Homogeneous Groups
11	45	127.272	X
10	46	211.091	X

Contrast	Difference	+/- Limits
10 - 11	*83.8186	12.0147

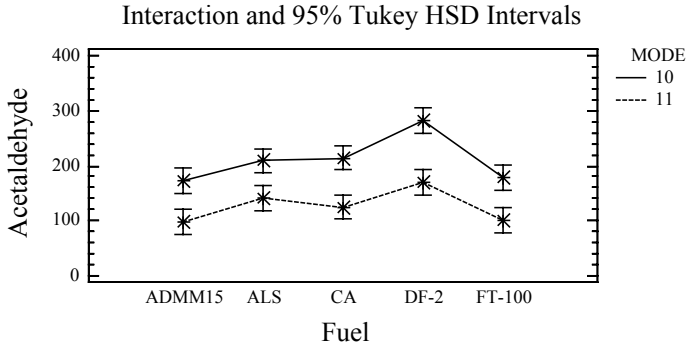
* denotes a statistically significant difference.



CONCLUSION: The trends in the average acetaldehyde across the pilot conditions for the CA and ALS fuels appear similar. While the ADMM15 fuel demonstrates an increase in the aveerage acetaldehyde from the Pilot A to Pilot B conditions, the CA and ALS fuels showed a decrease.



CONCLUSION: A significant interaction exists between the pilot condition and the modes. The difference in the average acetaldehyde between the two modes at the LPP condition is smaller than the differences at the Pilot A and Pilot B conditions.



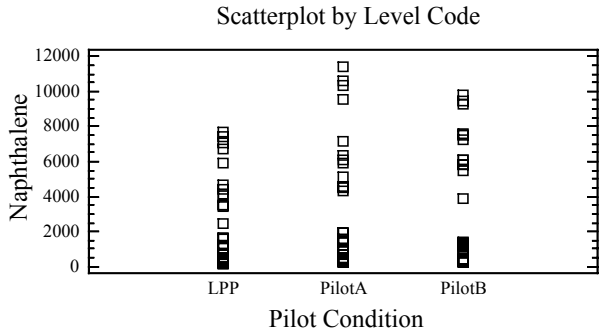
CONCLUSION: There is no significant interaction in the average acetaldehyde among the fuel and mode combinations.

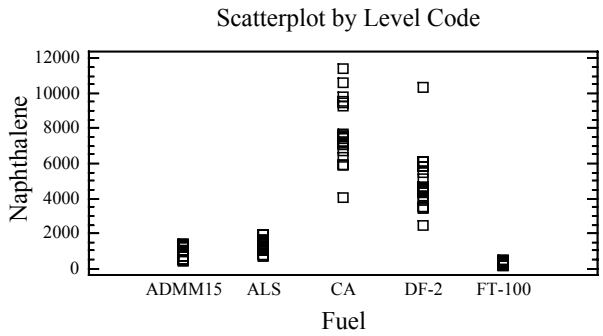
Multifactor ANOVA - NAPHTHALENE (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

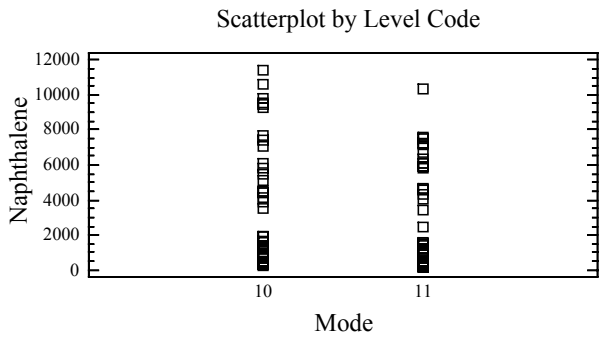
Analysis Summary

Dependent variable: GNAPHTH
Factors:
COND
FUEL
MODE

Number of complete cases: 91







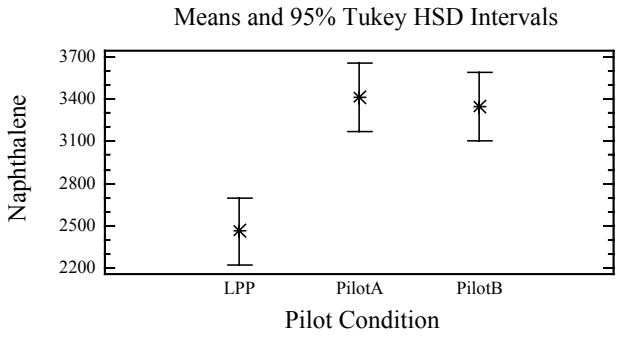
Analysis of Variance for GNAPHTH - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	1.74687E7	2	8.73433E6	14.33	0.0000
B:FUEL	7.55174E8	4	1.88793E8	309.67	0.0000
C:MODE	6.71152E6	1	6.71152E6	11.01	0.0015

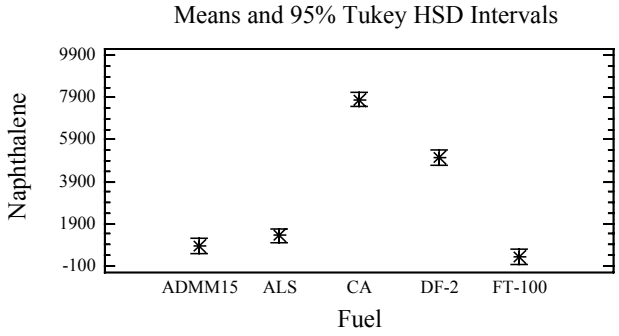
INTERACTIONS					
AB	1.5257E7	8	1.90713E6	3.13	0.0050
AC	664459.0	2	332230.0	0.54	0.5827
BC	2.70728E7	4	6.76821E6	11.10	0.0000
ABC	6.49723E6	8	812154.0	1.33	0.2451
RESIDUAL	3.71891E7	61	609658.0		
TOTAL (CORRECTED)	8.66535E8	90			

All F-ratios are based on the residual mean square error.

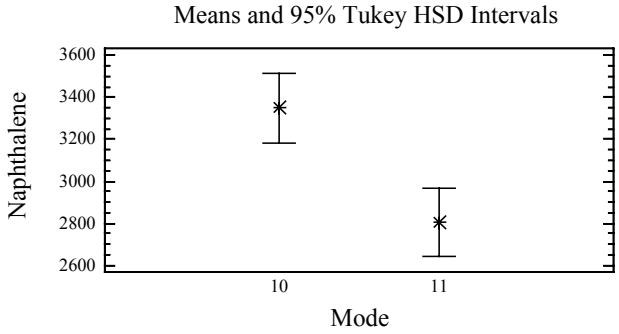
CONCLUSION: Statistically significant differences in the average naphthalene among the fuels, modes, pilot conditions, the pilot condition*fuel interaction, and the fuel*mode interaction.



CONCLUSION: The average naphthalene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: The average naphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels. The ALS and FT-100 fuels demonstrate significantly different average naphthalene; however, neither one of these fuels was significantly different than the ADMM15 fuel.



CONCLUSION: The average naphthalene for modes 10 and 11 are significantly different from one another.

Multiple Range Tests for GNAPHTH by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	2458.83	X
PilotB	30	3350.27	X
PilotA	30	3417.32	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-958.492	480.409
LPP - PilotB	*-891.437	480.409
PilotA - PilotB	67.0549	484.33

* denotes a statistically significant difference.

Multiple Range Tests for GNAPHTH by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	323.888	X
ADMM15	18	872.03	XX
ALS	19	1322.76	X
DF-2	18	5046.16	X
CA	18	7812.53	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-450.729	721.946
ADMM15 - CA	*-6940.5	731.637
ADMM15 - DF-2	*-4174.13	731.637
ADMM15 - FT-100	548.142	731.637
ALS - CA	*-6489.77	721.946
ALS - DF-2	*-3723.4	721.946
ALS - FT-100	*998.871	721.946
CA - DF-2	*2766.36	731.637
CA - FT-100	*7488.64	731.637
DF-2 - FT-100	*4722.28	731.637

* denotes a statistically significant difference.

Multiple Range Tests for GNAPHTH by MODE

```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
11             45        2803.53           X
10             46        3347.41            X
-------------------------------------------------------------------------------
Contrast                                 Difference           +/-  Limits
-------------------------------------------------------------------------------
10 - 11                                 *543.879             327.362
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
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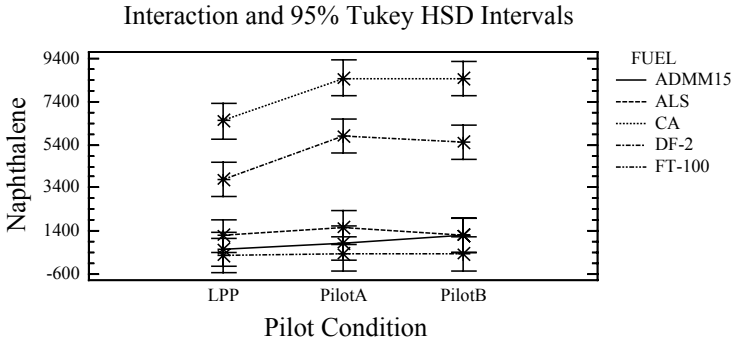
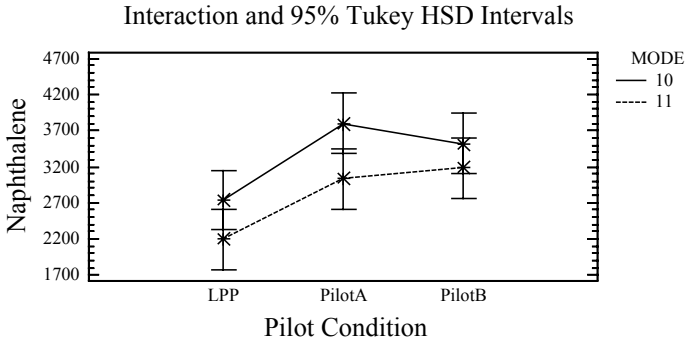
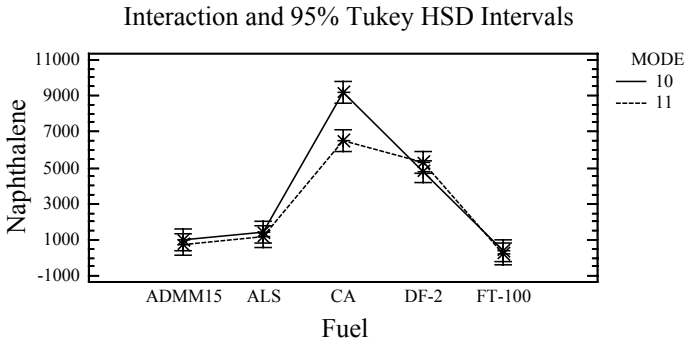


CONCLUSION: The trend in the average naphthalene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trends for the CA and DF-2 fuels. Whereas the trends in the ADMM15, ALS, and FT-100 fuels across the three pilot conditions are relatively constant, the CA and DF-2 fuels show an increase in the average naphthalene from the LPP to the Pilot A and Pilot B conditions.



CONCLUSION: There is no significant interaction in the average naphthalene among the mode and pilot condition combinations.



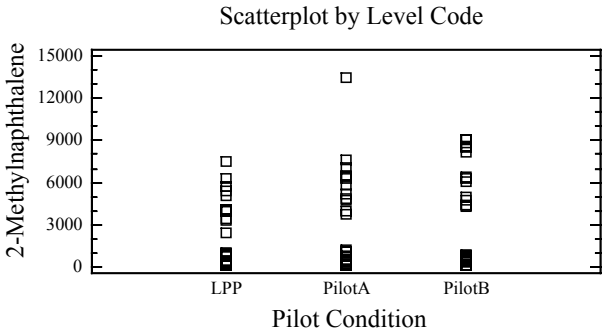
CONCLUSION: A significant interaction exists between the fuels and modes. The difference in the average naphthalene between the two modes is significant at the CA fuel. However, the remaining four fuels do not demonstrate a significant difference between the two modes with respect to the average naphthalene.

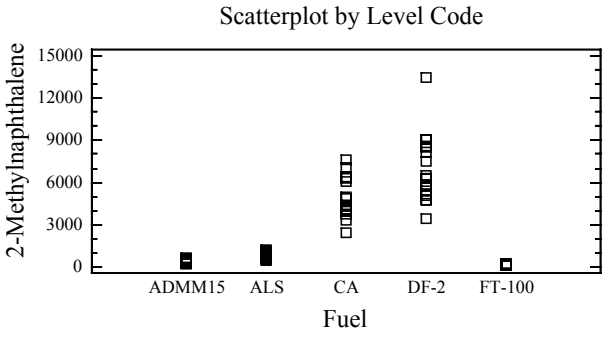
Multifactor ANOVA - 2-Methylnaphthalene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

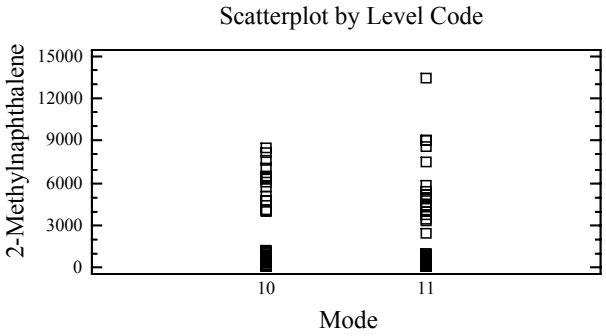
Analysis Summary

Dependent variable: METHYL2
Factors:
COND
FUEL
MODE

Number of complete cases: 91







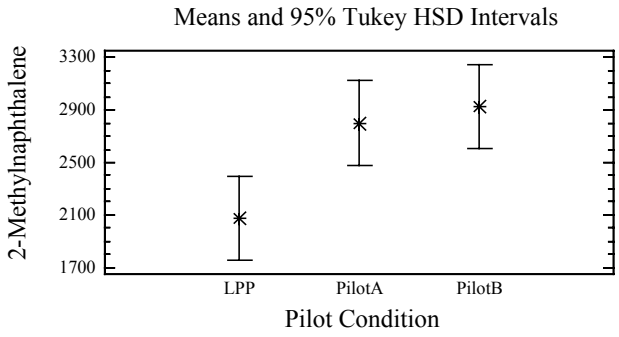
Analysis of Variance for METHYL2 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	1.30211E7	2	6.51055E6	6.11	0.0038
B:FUEL	6.84386E8	4	1.71097E8	160.63	0.0000
C:MODE	681627.0	1	681627.0	0.64	0.4268

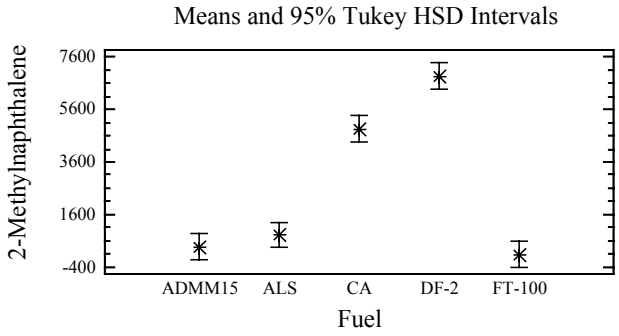
INTERACTIONS					
AB	2.06216E7	8	2.5777E6	2.42	0.0243
AC	164595.0	2	82297.7	0.08	0.9257
BC	2.10818E7	4	5.27045E6	4.95	0.0016
ABC	8.59668E6	8	1.07459E6	1.01	0.4390
RESIDUAL	6.49747E7	61	1.06516E6		
TOTAL (CORRECTED)	8.13672E8	90			

All F-ratios are based on the residual mean square error.

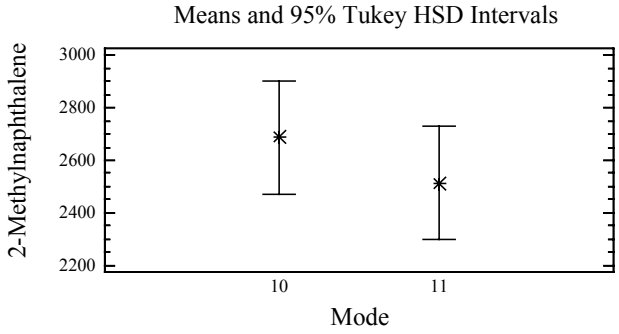
CONCLUSION: Statistically significant differences in the average 2-methylnaphthalene among the pilot conditions, fuels, pilot condition*fuel interaction, and the fuel*mode interaction.



CONCLUSION: The average 2-methylnaphthalene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: The average 2-methylnaphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels. The average 2-methylnaphthalene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average 2-methylnaphthalene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for METHYL2 by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	2072.28	X
PilotA	30	2799.98	X
PilotB	30	2929.34	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-727.694	635.002
LPP - PilotB	*-857.061	635.002
PilotA - PilotB	-129.367	640.186

* denotes a statistically significant difference.

Multiple Range Tests for METHYL2 by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	84.6176	X
ADMM15	18	376.432	X
ALS	19	802.859	X
CA	18	4868.56	X
DF-2	18	6870.21	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-426.427	954.265
ADMM15 - CA	*-4492.13	967.075
ADMM15 - DF-2	*-6493.78	967.075
ADMM15 - FT-100	291.815	967.075
ALS - CA	*-4065.7	954.265
ALS - DF-2	*-6067.35	954.265
ALS - FT-100	718.242	954.265
CA - DF-2	*-2001.65	967.075
CA - FT-100	*4783.94	967.075
DF-2 - FT-100	*6785.59	967.075

* denotes a statistically significant difference.

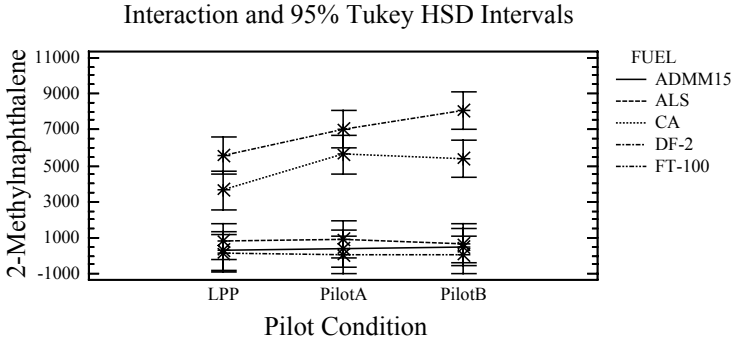
Multiple Range Tests for METHYL2 by MODE

Method: 95.0 percent Tukey HSD

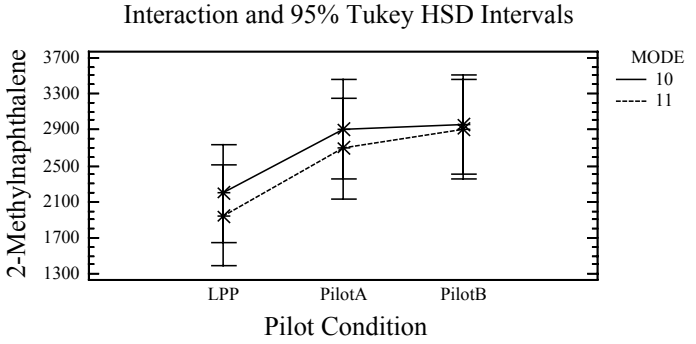
MODE	Count	LS Mean	Homogeneous Groups
11	45	2513.87	X
10	46	2687.2	X

Contrast	Difference	+/- Limits
10 - 11	173.327	432.705

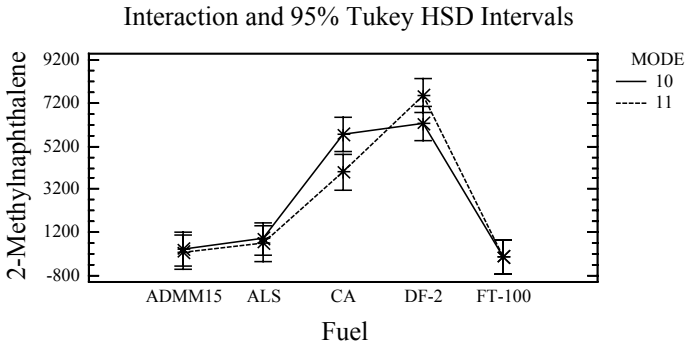
* denotes a statistically significant difference.



CONCLUSION: The trend in the average 2-methylnaphthalene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trends for the CA and DF-2 fuels. Whereas the trends in the ADMM15, ALS, and FT-100 fuels across the three pilot conditions are relatively constant, the CA and DF-2 fuels show an increase in the average 2-methylnaphthalene from the LPP to the Pilot A and Pilot B conditions.



CONCLUSION: There is no significant interaction in the average 2-methylnaphthalene among the mode and pilot condition combinations.



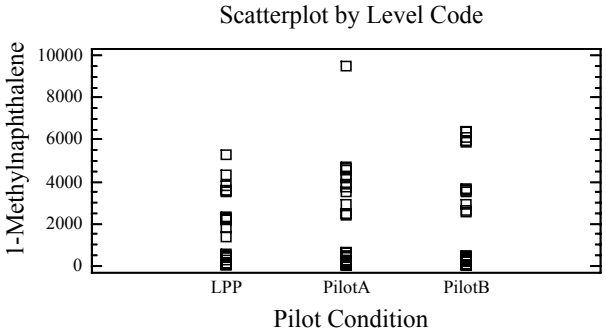
CONCLUSION: A significant interaction exists between the fuels and modes. The difference in the average 2-methylnaphthalene between the two modes is significant at the CA fuel. However, the remaining four fuels do not demonstrate a significant difference between the two modes with respect to the average 2-methylnaphthalene.

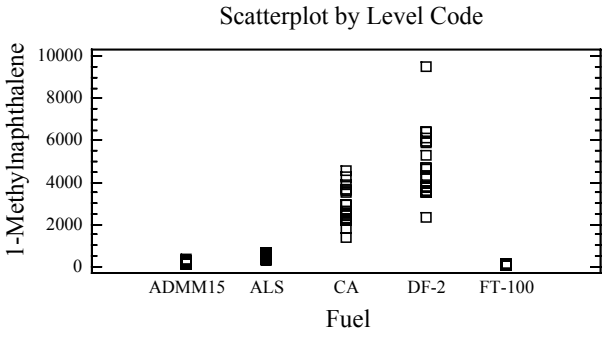
Multifactor ANOVA - 1-Methylnaphthalene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

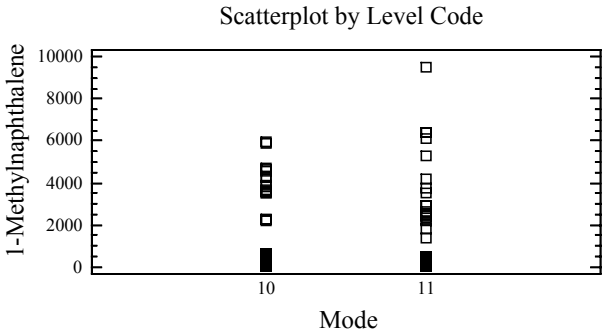
Analysis Summary

Dependent variable: METHYL1
Factors:
COND
FUEL
MODE

Number of complete cases: 91







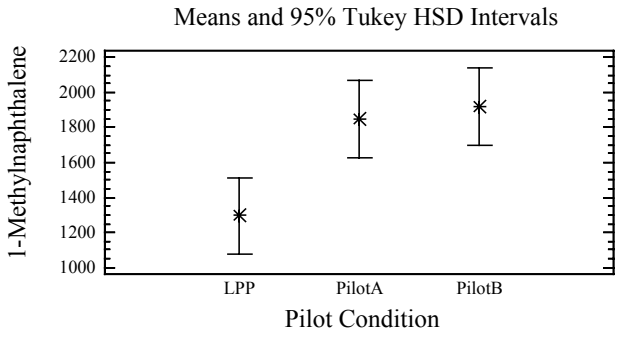
Analysis of Variance for METHYL1 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	7.1201E6	2	3.56005E6	7.02	0.0018
B:FUEL	3.2382E8	4	8.0955E7	159.66	0.0000
C:MODE	104049.0	1	104049.0	0.21	0.6522

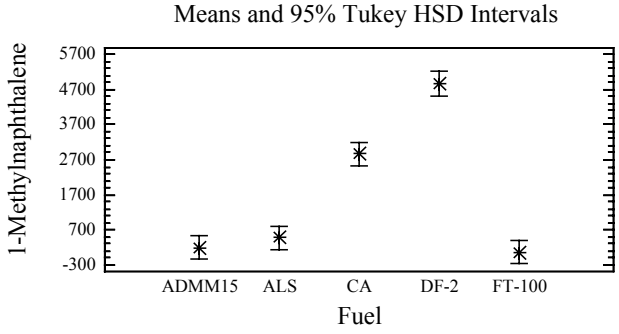
INTERACTIONS					
AB	1.10994E7	8	1.38742E6	2.74	0.0120
AC	87299.1	2	43649.5	0.09	0.9176
BC	7.60607E6	4	1.90152E6	3.75	0.0086
ABC	3.4431E6	8	430387.0	0.85	0.5640
RESIDUAL	3.09295E7	61	507040.0		
TOTAL (CORRECTED)	3.8428E8	90			

All F-ratios are based on the residual mean square error.

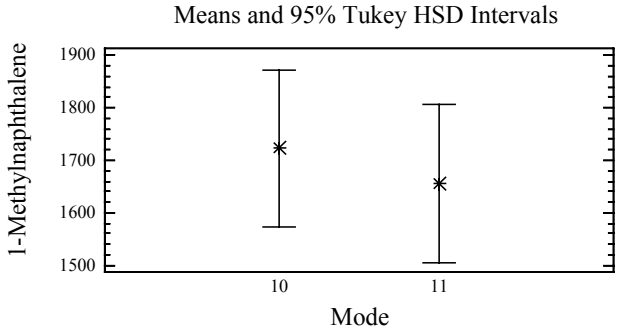
CONCLUSION: Statistically significant differences in the average 1-methylnaphthalene among the pilot conditions, fuels, pilot condition*fuel interaction, and fuel*mode interaction.



CONCLUSION: The average 1-methylnaphthalene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: The average 1-methylnaphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels. The average 1-methylnaphthalene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average 1-methylnaphthalene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for METHYL1 by COND

Method: 95.0 percent Tukey HSD

COND	Count	LS Mean	Homogeneous Groups
LPP	31	1296.69	X
PilotA	30	1847.77	X
PilotB	30	1922.05	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-551.08	438.116
LPP - PilotB	*-625.36	438.116
PilotA - PilotB	-74.2805	441.692

* denotes a statistically significant difference.

Multiple Range Tests for METHYL1 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	53.4942	X
ADMM15	18	185.723	X
ALS	19	468.028	X
CA	18	2868.42	X
DF-2	18	4868.5	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-282.306	658.39
ADMM15 - CA	*-2682.69	667.228
ADMM15 - DF-2	*-4682.78	667.228
ADMM15 - FT-100	132.229	667.228
ALS - CA	*-2400.39	658.39
ALS - DF-2	*-4400.47	658.39
ALS - FT-100	414.534	658.39
CA - DF-2	*-2000.09	667.228
CA - FT-100	*2814.92	667.228
DF-2 - FT-100	*4815.01	667.228

* denotes a statistically significant difference.

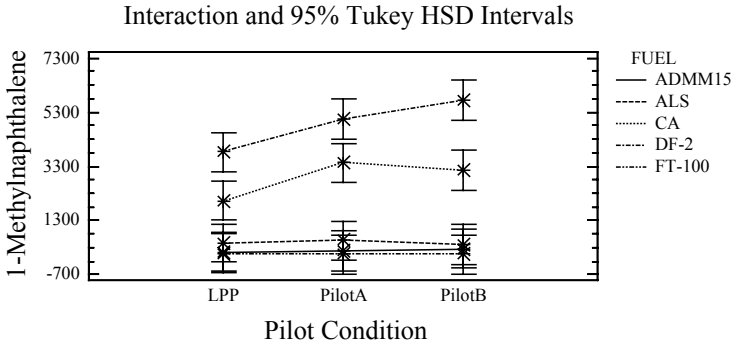
Multiple Range Tests for METHYL1 by MODE

Method: 95.0 percent Tukey HSD

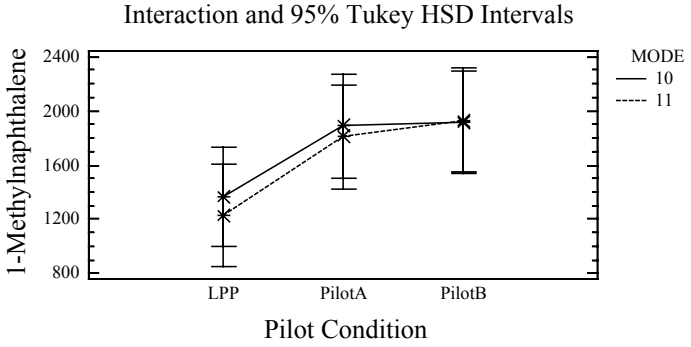
MODE	Count	LS Mean	Homogeneous Groups
11	45	1654.97	X
10	46	1722.69	X

Contrast	Difference	+/- Limits
10 - 11	67.7191	298.542

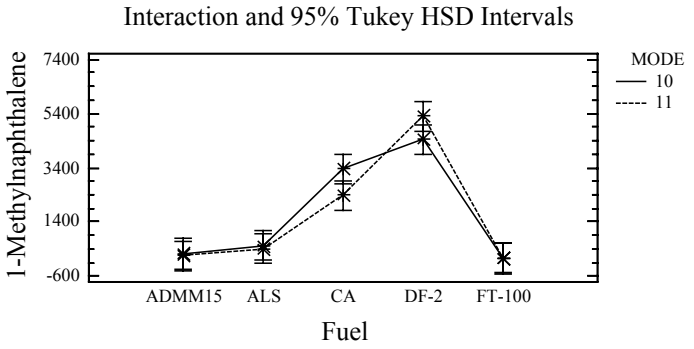
* denotes a statistically significant difference.



CONCLUSION: The trend in the average 1-methylnaphthalene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trends for the CA and DF-2 fuels. Whereas the trends in the ADMM15, ALS, and FT-100 fuels across the three pilot conditions are relatively constant, the CA and DF-2 fuels show an increase in the average 1-methylnaphthalene from the LPP to the Pilot A and Pilot B conditions.



CONCLUSION: There is no significant interaction in the average 1-methylnapthalene among the mode and pilot condition combinations.



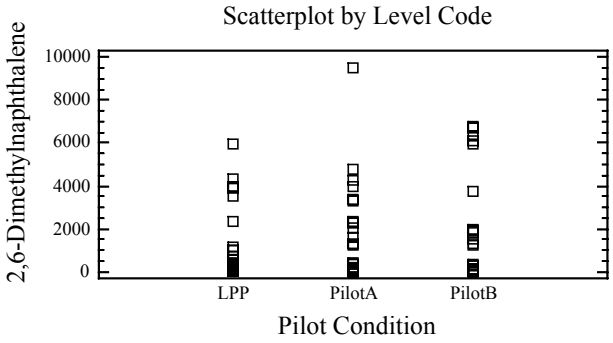
CONCLUSION: A significant interaction exists between the fuels and modes. The difference in the average 1-methylnaphthalene between the two modes is significant at the CA fuel. However, the remaining four fuels do not demonstrate a significant difference between the two modes with respect to the average 1-methylnaphthalene.

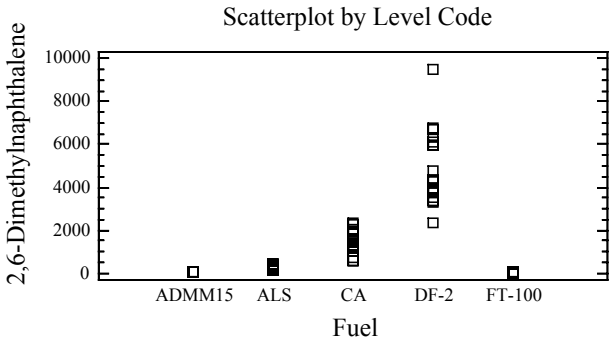
Multifactor ANOVA - 2,6-Dimethylnaphthalene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

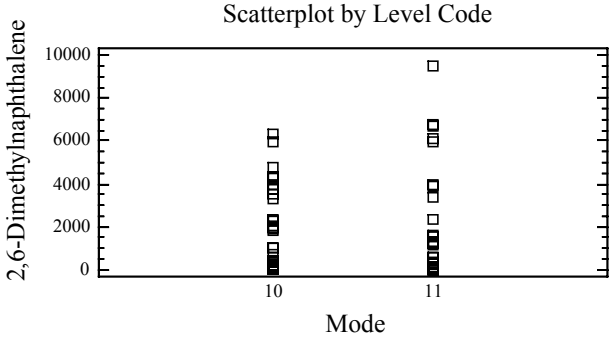
Analysis Summary

Dependent variable: DIMETHYL
Factors:
COND
FUEL
MODE

Number of complete cases: 91







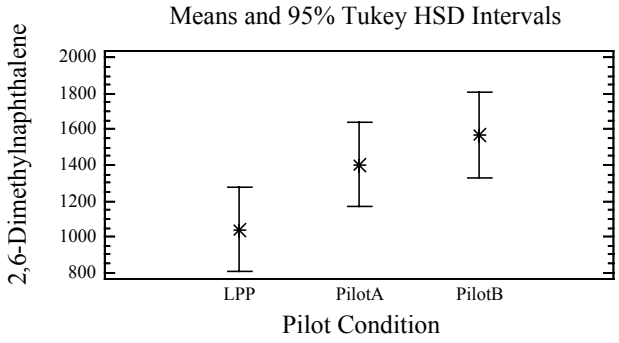
Analysis of Variance for DIMETHYL - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	4.46581E6	2	2.23291E6	3.83	0.0270
B:FUEL	3.15153E8	4	7.87882E7	135.30	0.0000

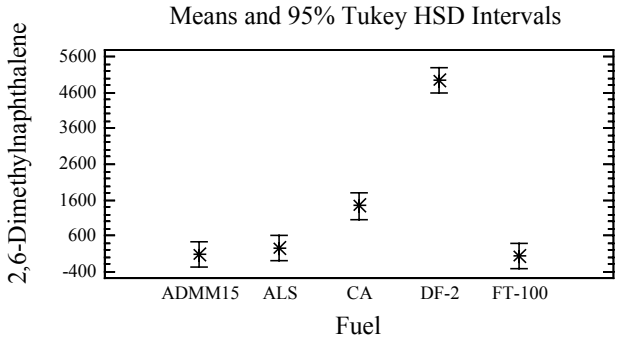
C:MODE	106897.0	1	106897.0	0.18	0.6698
INTERACTIONS					
AB	1.02244E7	8	1.27804E6	2.19	0.0401
AC	92309.3	2	46154.7	0.08	0.9239
BC	5.23499E6	4	1.30875E6	2.25	0.0743
ABC	1.90357E6	8	237947.0	0.41	0.9114
RESIDUAL	3.55226E7	61	582338.0		
TOTAL (CORRECTED)	3.72663E8	90			

All F-ratios are based on the residual mean square error.

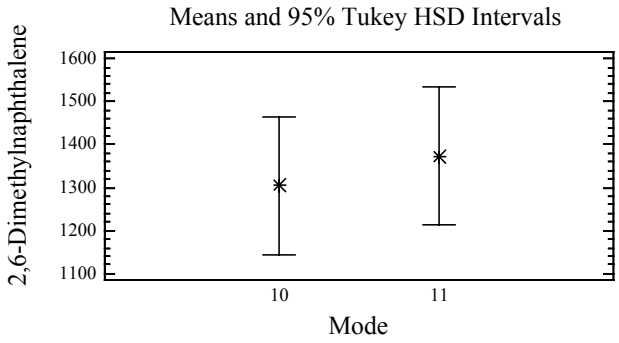
CONCLUSION: Statistically significant differences in the average 2,6-dimethylnaphthalene among the pilot conditions, fuels, and pilot condition*fuel interaction.



CONCLUSION: The average 2,6-dimethylnaphthalene for the Pilot B condition is significantly different than the LPP condition.



CONCLUSION: The average 2,6-dimethylnaphthalene for the CA and DF-2 fuels are significantly different from one another and the remaining three fuels. The average 2,6-dimethylnaphthalene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average 2,6-dimethylnaphthalene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for DIMETHYL by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	1040.88	X
PilotA	30	1404.39	XX
PilotB	30	1570.21	X

Contrast	Difference	+/- Limits
LPP - PilotA	-363.515	469.521
LPP - PilotB	*-529.328	469.521
PilotA - PilotB	-165.813	473.354

* denotes a statistically significant difference.

Multiple Range Tests for DIMETHYL by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	33.1233	X
ADMM15	18	61.705	X
ALS	19	237.558	X
CA	18	1429.7	X
DF-2	18	4930.39	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-175.853	705.585
ADMM15 - CA	*-1367.99	715.056
ADMM15 - DF-2	*-4868.68	715.056
ADMM15 - FT-100	28.5817	715.056
ALS - CA	*-1192.14	705.585
ALS - DF-2	*-4692.83	705.585
ALS - FT-100	204.435	705.585
CA - DF-2	*-3500.69	715.056
CA - FT-100	*1396.58	715.056
DF-2 - FT-100	*4897.26	715.056

* denotes a statistically significant difference.

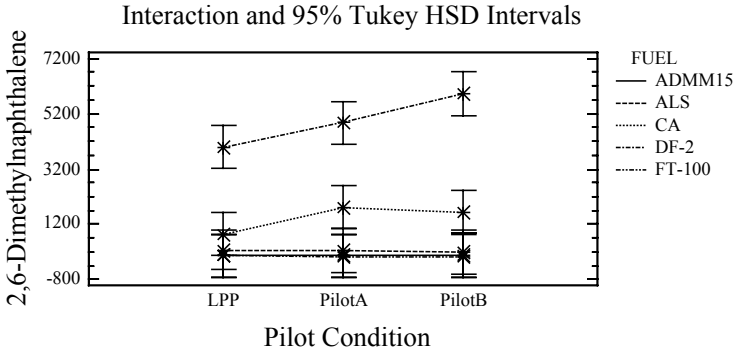
Multiple Range Tests for DIMETHYL by MODE

Method: 95.0 percent Tukey HSD

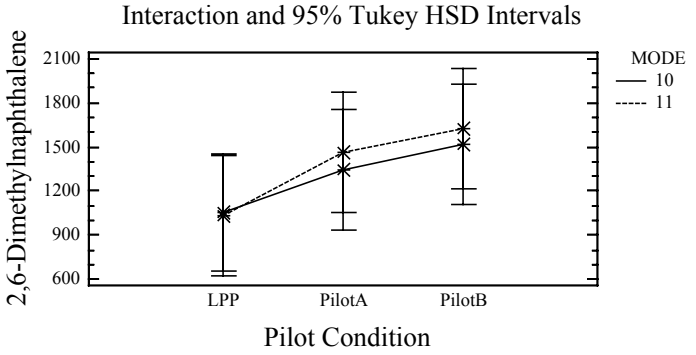
MODE	Count	LS Mean	Homogeneous Groups
10	46	1304.17	X
11	45	1372.81	X

Contrast	Difference	+/- Limits
10 - 11	-68.6395	319.943

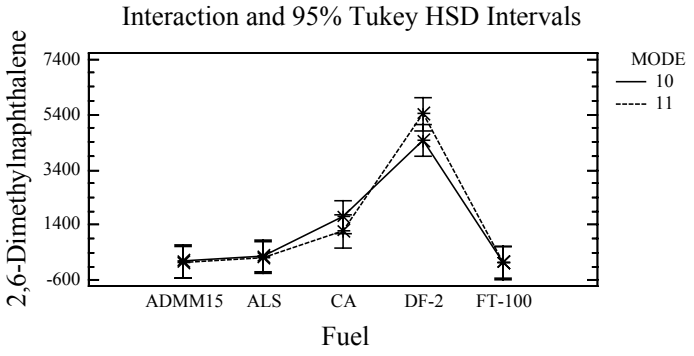
* denotes a statistically significant difference.



CONCLUSION: The trend in the average 2,6-dimethylnaphthalene across the pilot conditions for the ADMM16, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average 2,6-dimethylnaphthalene from the LPP to the Pilot A and Pilot B conditions.



CONCLUSION: There is no significant interaction in the average 2,6-dimethylnaphthalene among the pilot condition and mode combinations.



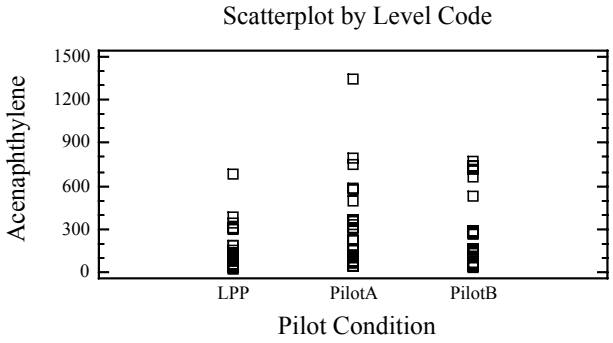
CONCLUSION: There is no significant interaction in the average 2,6-dimethylnaphthalene among the fuel and mode combinations.

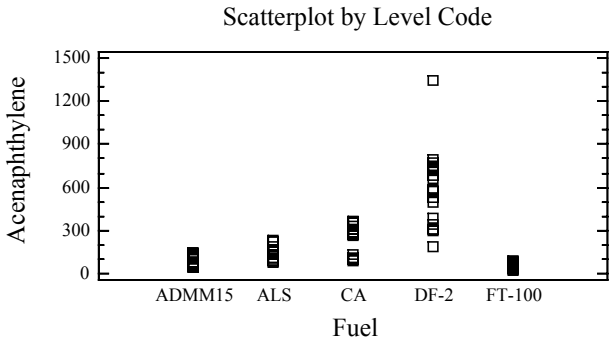
Multifactor ANOVA - Acenaphthylene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

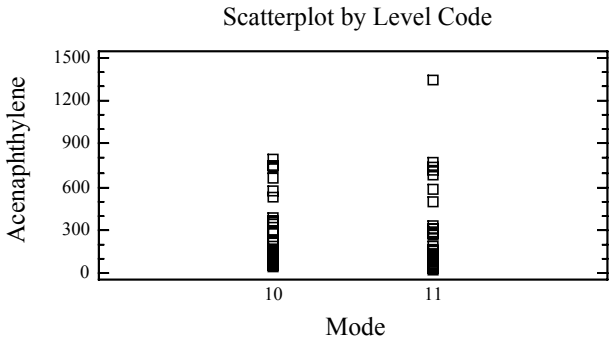
Analysis Summary

Dependent variable: GACENAPH
Factors:
COND
FUEL
MODE

Number of complete cases: 91







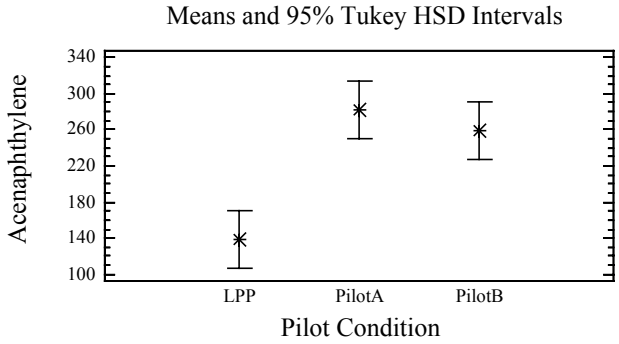
Analysis of Variance for GACENAPH - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	361412.0	2	180706.0	16.84	0.0000
B:FUEL	3.59924E6	4	899810.0	83.86	0.0000

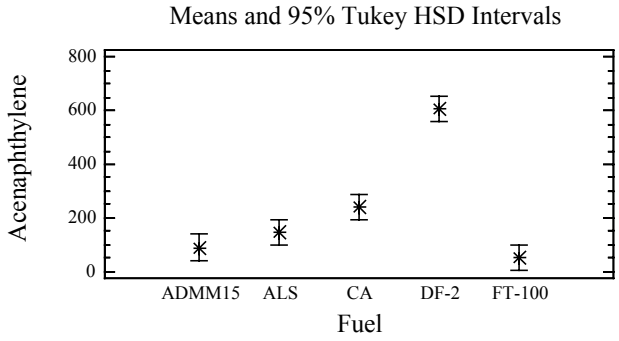
C:MODE	45.4556	1	45.4556	0.00	0.9483
INTERACTIONS					
AB	381971.0	8	47746.4	4.45	0.0003
AC	973.496	2	486.748	0.05	0.9557
BC	41481.9	4	10370.5	0.97	0.4325
ABC	5332.37	8	666.546	0.06	0.9998
RESIDUAL	654523.0	61	10729.9		
TOTAL (CORRECTED)	5.04131E6	90			

All F-ratios are based on the residual mean square error.

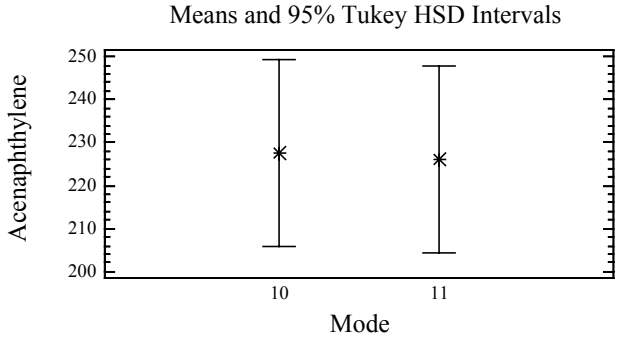
CONCLUSION: Statistically significant differences in the average acenaphthylene among the pilot conditions, fuels, and pilot condition*fuel interaction.



CONCLUSION: The average acenaphthylene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP conditions.



CONCLUSION: There are several distinct fuel groupings with respect to the average acenaphthalene. The average acenaphthalene for the DF-2 fuel is significantly different from the remaining four fuels. The CA fuel is significantly different than the ADMM15 and FT-100 fuels, but not significantly different than the ALS fuel.



CONCLUSION: The average acenaphthalene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for GACENAPH by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	138.991	X
PilotB	30	259.347	X
PilotA	30	282.307	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-143.316	63.7331
LPP - PilotB	*-120.355	63.7331
PilotA - PilotB	22.9605	64.2534

* denotes a statistically significant difference.

Multiple Range Tests for GACENAPH by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	52.0377	X
ADMM15	18	89.6773	X
ALS	19	147.393	XX
CA	18	239.183	X
DF-2	18	606.118	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-57.7156	95.7766
ADMM15 - CA	*-149.505	97.0622
ADMM15 - DF-2	*-516.441	97.0622
ADMM15 - FT-100	37.6396	97.0622
ALS - CA	-91.7897	95.7766
ALS - DF-2	*-458.725	95.7766
ALS - FT-100	95.3552	95.7766
CA - DF-2	*-366.935	97.0622
CA - FT-100	*187.145	97.0622
DF-2 - FT-100	*554.08	97.0622

* denotes a statistically significant difference.

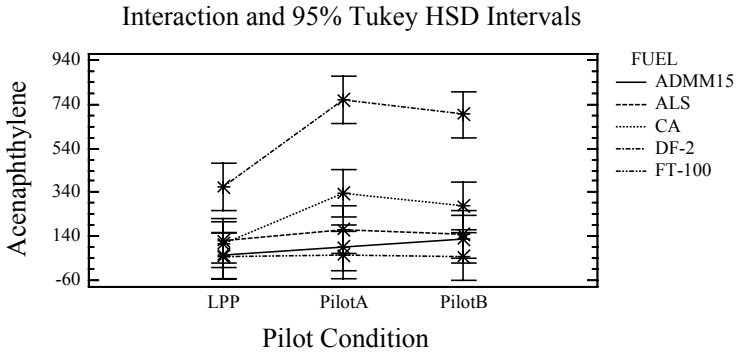
Multiple Range Tests for GACENAPH by MODE

Method: 95.0 percent Tukey HSD

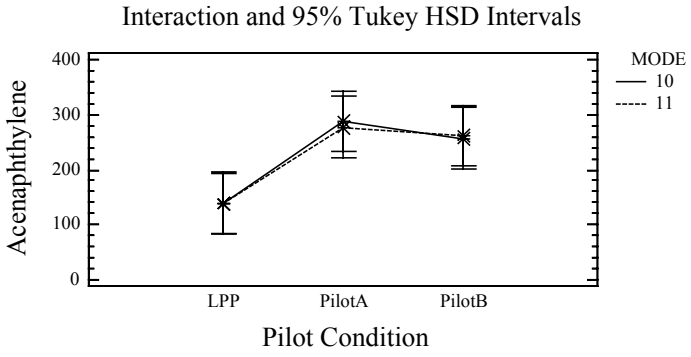
MODE	Count	LS Mean	Homogeneous Groups
11	45	226.174	X
10	46	227.589	X

Contrast	Difference	+/- Limits
10 - 11	1.41542	43.4292

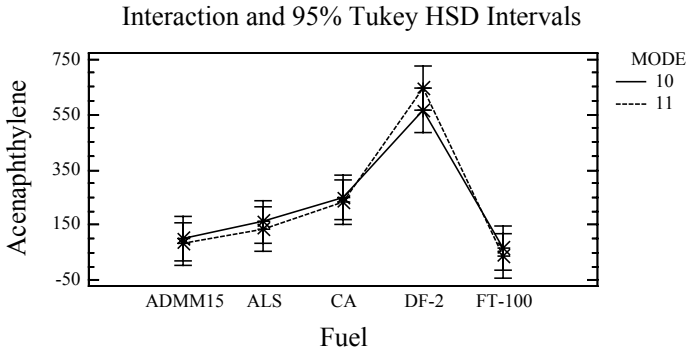
* denotes a statistically significant difference.



CONCLUSION: The trend in the average acenaphthalene across the pilot conditions for the ADMM15, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average acenaphthalene from the LPP to the Pilot A and Pilot B conditions.



CONCLUSION: There is no significant interaction in the average acenaphthalene among the pilot condition and mode combinations.



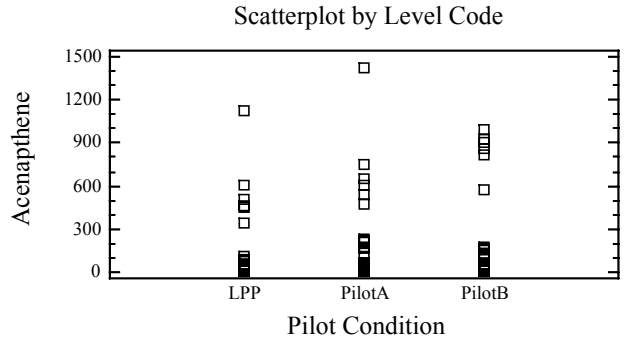
CONCLUSION: There is no significant interaction in the average acenaphthalene among the fuel and mode combinations.

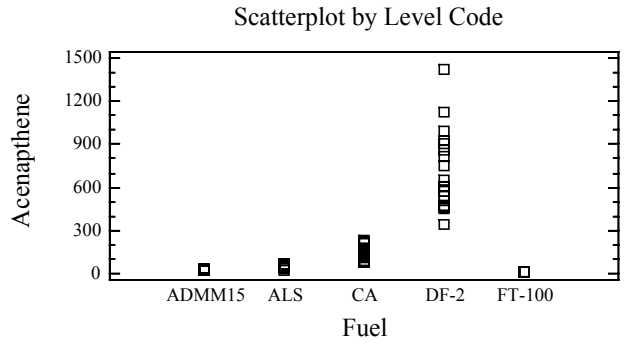
Multifactor ANOVA - Acenaphthene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

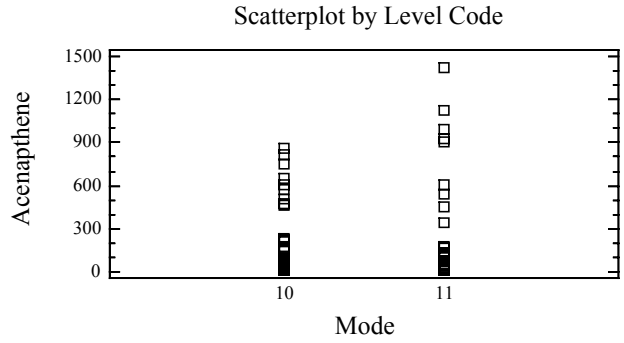
Analysis Summary

Dependent variable: ACENAPTH
Factors:
COND
FUEL
MODE

Number of complete cases: 91







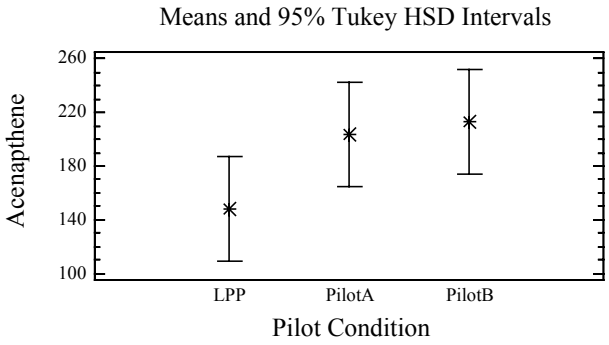
Analysis of Variance for ACENAPTH - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	75508.4	2	37754.2	2.40	0.0989
B:FUEL	6.6314E6	4	1.65785E6	105.57	0.0000
C:MODE	13127.1	1	13127.1	0.84	0.3642

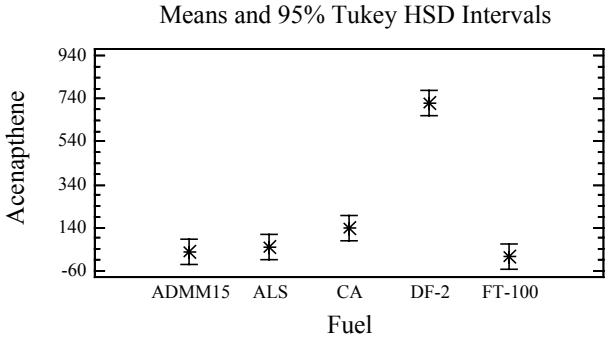
INTERACTIONS					
AB	170019.0	8	21252.3	1.35	0.2353
AC	112.754	2	56.3768	0.00	0.9964
BC	133598.0	4	33399.5	2.13	0.0883
ABC	15184.1	8	1898.01	0.12	0.9982
RESIDUAL	957924.0	61	15703.7		
TOTAL (CORRECTED)	8.00012E6	90			

All F-ratios are based on the residual mean square error.

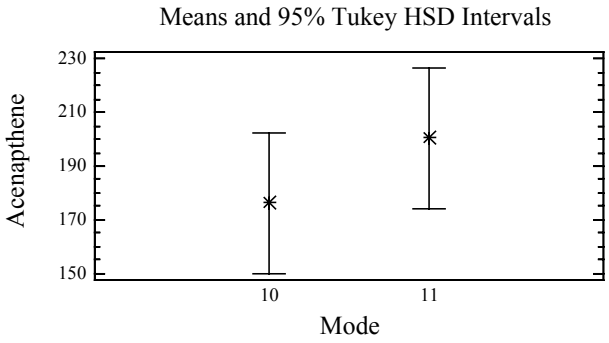
CONCLUSION: Statistically significant differences in the average acenaphthene among the fuels.



CONCLUSION: The average acenaphthene for the three pilot conditions are not significantly different from one another.



CONCLUSION: There are several distinct fuel groupings with respect to the average acenaphthene. The average acenaphthene for the DF-2 fuel is significantly different than the remaining four fuels. Also, the CA fuel is significantly different than the FT-100 fuel, but not significantly different than the ADMM15 or ALS fuels.



CONCLUSION: The average acenaphthene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for ACENAPTH by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	148.117	X
PilotA	30	203.4	X
PilotB	30	213.462	X

Contrast	Difference	+/- Limits
LPP - PilotA	-55.2838	77.1025
LPP - PilotB	-65.3452	77.1025
PilotA - PilotB	-10.0614	77.7319

* denotes a statistically significant difference.

Multiple Range Tests for ACENAPTH by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	7.88772	X
ADMM15	18	24.8077	XX
ALS	19	48.2916	XX
CA	18	137.46	X
DF-2	18	723.184	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-23.4839	115.868
ADMM15 - CA	-112.653	117.423
ADMM15 - DF-2	*-698.376	117.423
ADMM15 - FT-100	16.9199	117.423
ALS - CA	-89.1687	115.868
ALS - DF-2	*-674.892	115.868
ALS - FT-100	40.4039	115.868
CA - DF-2	*-585.723	117.423
CA - FT-100	*129.573	117.423
DF-2 - FT-100	*715.296	117.423

* denotes a statistically significant difference.

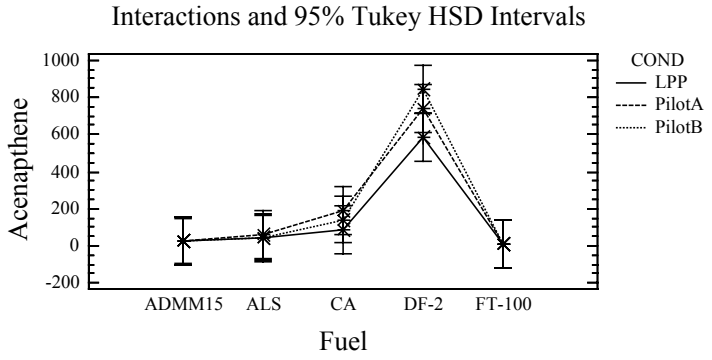
Multiple Range Tests for ACENAPTH by MODE

Method: 95.0 percent Tukey HSD

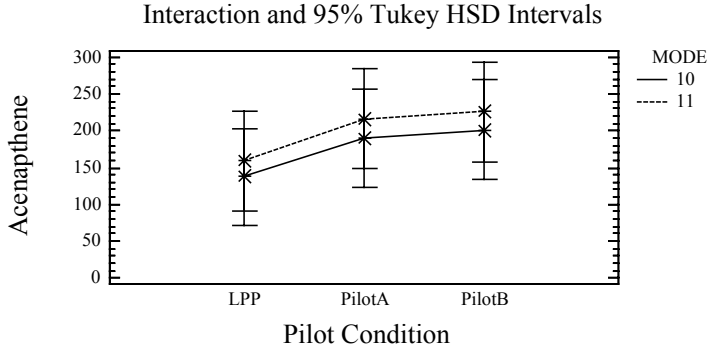
MODE	Count	LS Mean	Homogeneous Groups
10	46	176.3	X
11	45	200.353	X

Contrast	Difference	+/- Limits
10 - 11	-24.0534	52.5394

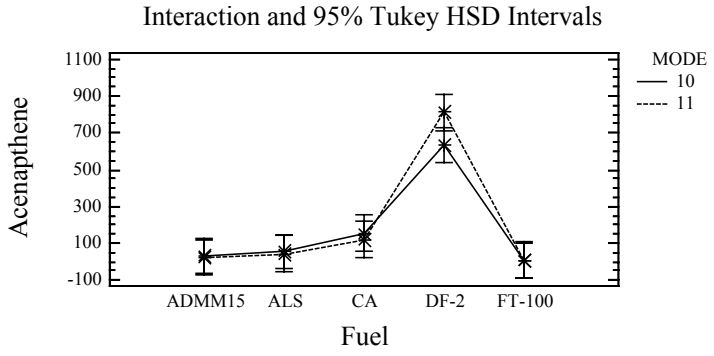
* denotes a statistically significant difference.



CONCLUSION: There is no significant interaction in the average acenaphthene among the fuel and pilot condition combinations.



CONCLUSION: There is no significant interaction in the average acenaphthene among the mode and pilot condition combinations.



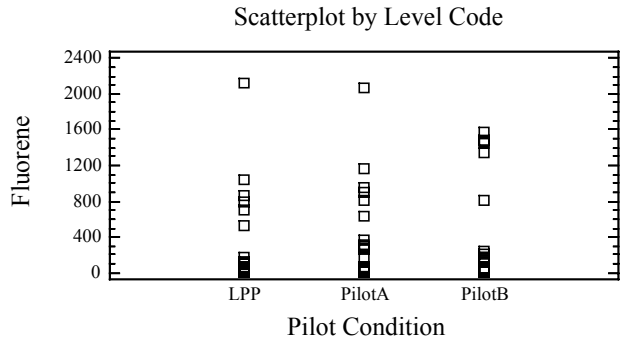
CONCLUSION: There is no significant interaction in the average acenaphthene among the fuel and mode combinations.

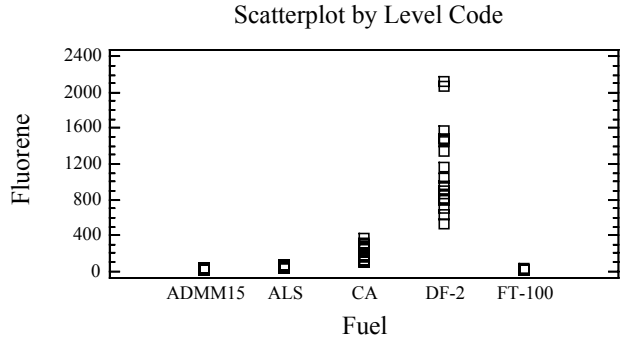
Multifactor ANOVA - Fluorene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

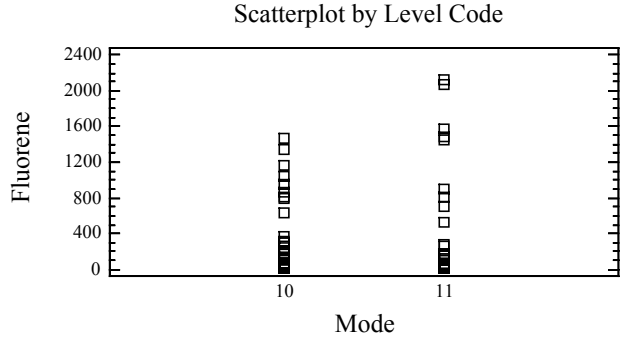
Analysis Summary

Dependent variable: GFLUOREN
Factors:
COND
FUEL
MODE

Number of complete cases: 91







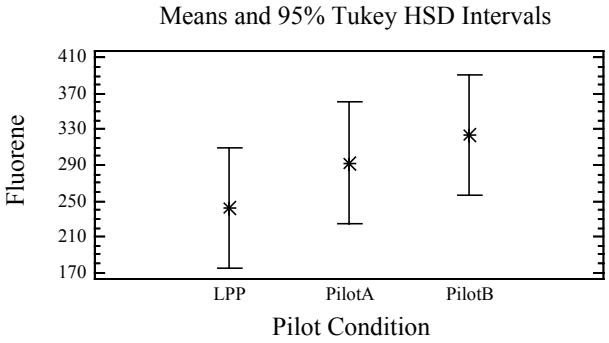
Analysis of Variance for GFLUOREN - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	102193.0	2	51096.4	1.06	0.3515
B:FUEL	1.72763E7	4	4.31907E6	89.92	0.0000
C:MODE	42733.1	1	42733.1	0.89	0.3493

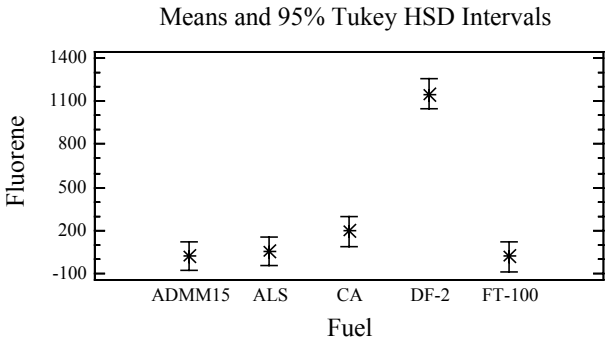
INTERACTIONS					
AB	373258.0	8	46657.3	0.97	0.4668
AC	24.422	2	12.211	0.00	0.9997
BC	336153.0	4	84038.3	1.75	0.1508
ABC	18556.1	8	2319.51	0.05	0.9999
RESIDUAL	2.93008E6	61	48034.1		
TOTAL (CORRECTED)	2.10864E7	90			

All F-ratios are based on the residual mean square error.

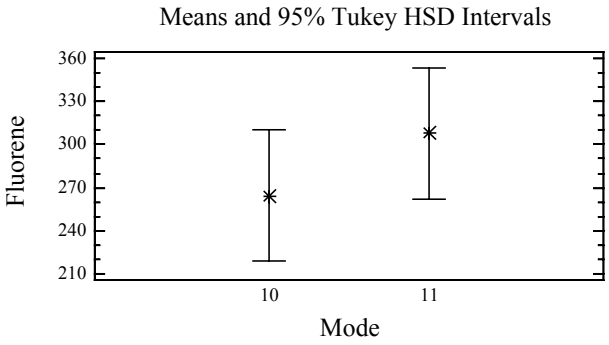
CONCLUSION: Statistically significant differences in the average fluorene among the fuels.



CONCLUSION: The average fluorene for the three pilot conditions are not significantly different from one another.



CONCLUSION: The average fluorene for the DF-2 fuel is significantly different than the remaining four fuels.



CONCLUSION: The average fluorene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for GFLUOREN by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	242.329	X
PilotA	30	292.421	X
PilotB	30	323.542	X

Contrast	Difference	+/- Limits
LPP - PilotA	-50.0916	134.847
LPP - PilotB	-81.2126	134.847
PilotA - PilotB	-31.121	135.948

* denotes a statistically significant difference.

Multiple Range Tests for GFLUOREN by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	14.2477	X
ADMM15	18	21.5123	X
ALS	19	50.0833	X
CA	18	193.028	X
DF-2	18	1151.61	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-28.5711	202.645
ADMM15 - CA	-171.515	205.366
ADMM15 - DF-2	*-1130.1	205.366
ADMM15 - FT-100	7.26459	205.366
ALS - CA	-142.944	202.645
ALS - DF-2	*-1101.53	202.645
ALS - FT-100	35.8357	202.645
CA - DF-2	*-958.587	205.366
CA - FT-100	178.78	205.366
DF-2 - FT-100	*1137.37	205.366

* denotes a statistically significant difference.

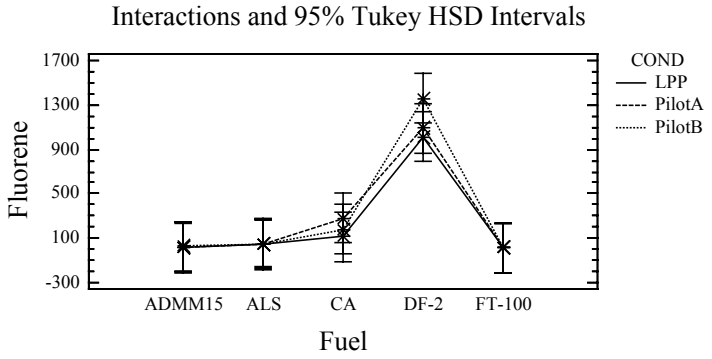
Multiple Range Tests for GFLUOREN by MODE

Method: 95.0 percent Tukey HSD

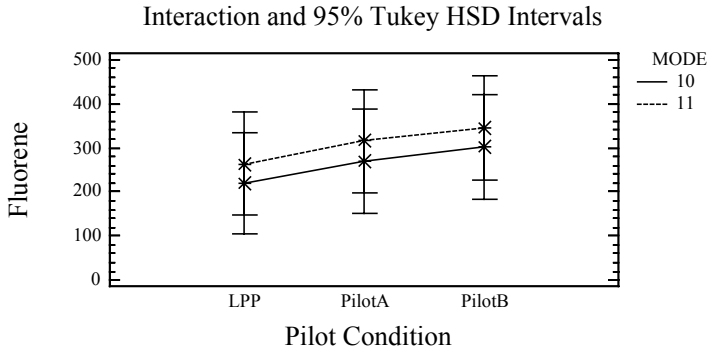
MODE	Count	LS Mean	Homogeneous Groups
10	46	264.398	X
11	45	307.796	X

Contrast	Difference	+/- Limits
10 - 11	-43.3984	91.8882

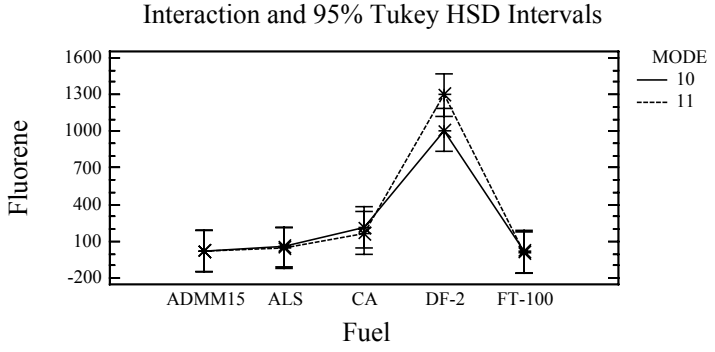
* denotes a statistically significant difference.



CONCLUSION: There is no significant interaction in the average fluorene among the fuel and pilot condition combinations.



CONCLUSION: There is no significant interaction in the average fluorene among the pilot condition and mode combinations.

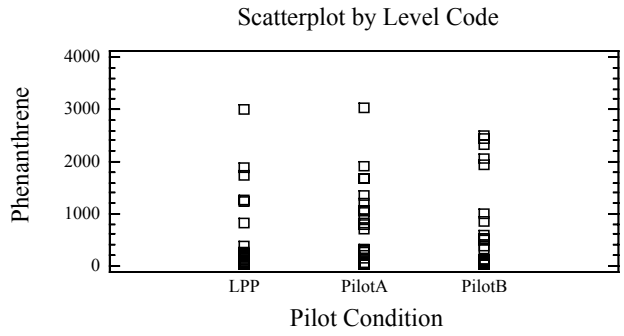


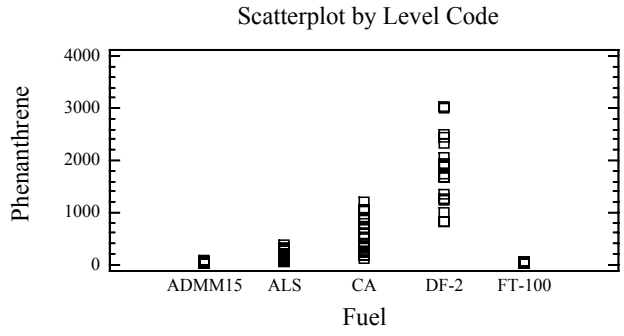
CONCLUSION: There is no significant interaction in the average fluorene among the fuel and mode combinations.

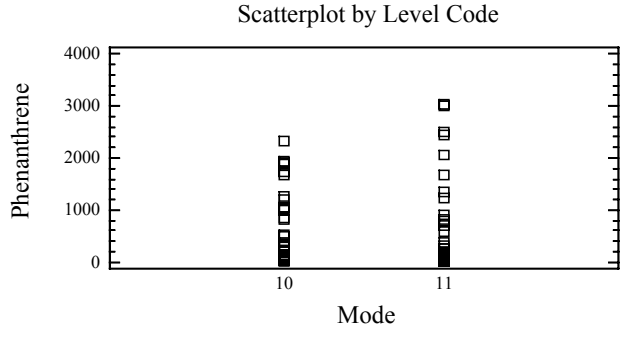
Multifactor ANOVA - Phenanthrene (micro g/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11
Analysis Summary

Dependent variable: GPHENANT
Factors:
COND
FUEL
MODE

Number of complete cases: 91







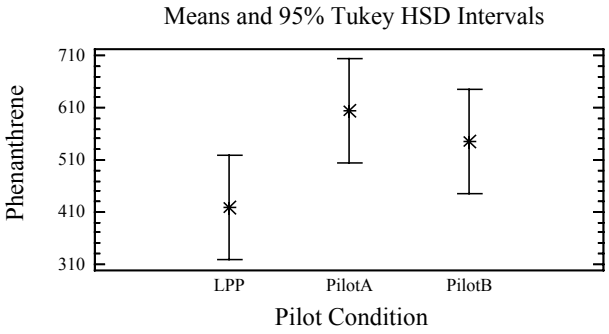
Analysis of Variance for GPHENANT - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	550944.0	2	275472.0	2.63	0.0801
B:FUEL	4.09606E7	4	1.02401E7	97.83	0.0000
C:MODE	15030.7	1	15030.7	0.14	0.7061

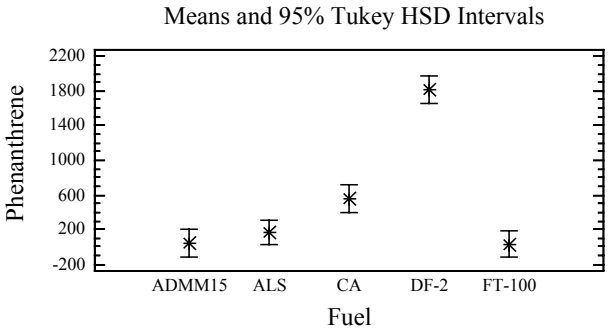
INTERACTIONS					
AB	1.77444E6	8	221804.0	2.12	0.0474
AC	22259.4	2	11129.7	0.11	0.8993
BC	828870.0	4	207218.0	1.98	0.1089
ABC	321701.0	8	40212.6	0.38	0.9250
RESIDUAL	6.38527E6	61	104676.0		
TOTAL (CORRECTED)	5.08462E7	90			

All F-ratios are based on the residual mean square error.

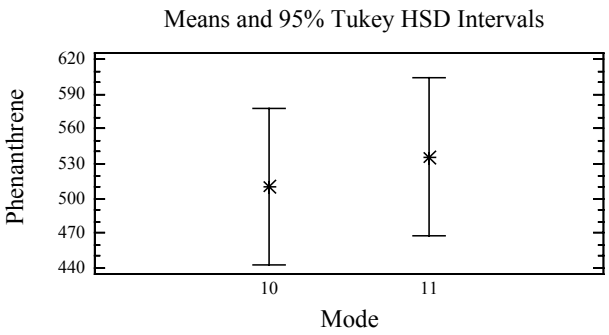
CONCLUSION: Statistically significant differences in the average phenanthrene among the fuels and pilot condition*fuel interaction.



CONCLUSION: No significant differences in the average phenanthrene among the three pilot conditions.



CONCLUSION: The average phenanthrene for the DF-2 and CA fuels is significantly different than the remaining three fuels. The average phenanthrene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average phenanthrene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for GPHENANT by COND

Method: 95.0 percent Tukey HSD

COND	Count	LS Mean	Homogeneous Groups
LPP	31	418.379	X
PilotB	30	545.882	X
PilotA	30	604.351	X

Contrast	Difference	+/- Limits
LPP - PilotA	-185.973	199.064
LPP - PilotB	-127.503	199.064
PilotA - PilotB	58.4694	200.689

* denotes a statistically significant difference.

Multiple Range Tests for GPHENANT by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	29.2336	X
ADMM15	18	43.1629	X
ALS	19	169.183	X
CA	18	557.58	X
DF-2	18	1815.19	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-126.02	299.148
ADMM15 - CA	*-514.417	303.164
ADMM15 - DF-2	*-1772.03	303.164
ADMM15 - FT-100	13.9293	303.164
ALS - CA	*-388.397	299.148
ALS - DF-2	*-1646.01	299.148
ALS - FT-100	139.949	299.148
CA - DF-2	*-1257.61	303.164
CA - FT-100	*528.346	303.164
DF-2 - FT-100	*1785.96	303.164

* denotes a statistically significant difference.

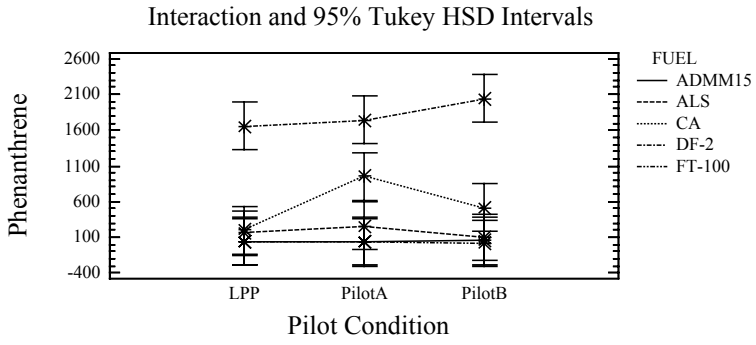
Multiple Range Tests for GPHENANT by MODE

Method: 95.0 percent Tukey HSD

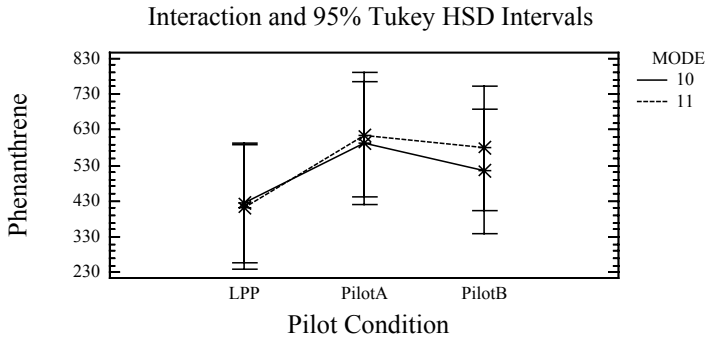
MODE	Count	LS Mean	Homogeneous Groups
10	46	510.002	X
11	45	535.74	X

Contrast	Difference	+/- Limits
10 - 11	-25.7384	135.647

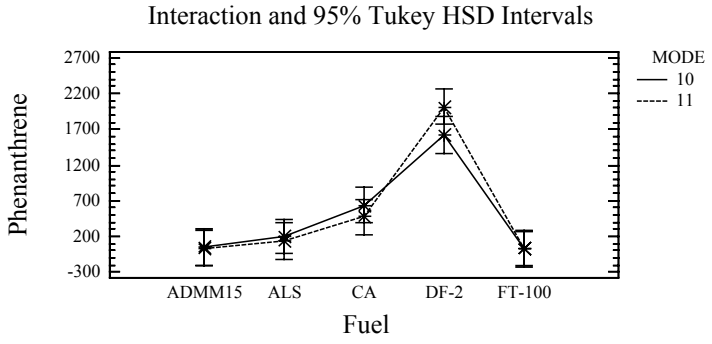
* denotes a statistically significant difference.



CONCLUSION: The trend in the average phenanthrene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is signficantly different than the trend for the DF-2 and CA fuels. Whereas, the trends in the ADMM15, ALS, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average phenanthrene from the LPP to the Pilot A and Pilot B conditions. Also, the CA fuel demonstrates an increase in the Pilot A condition.



CONCLUSION: There is no significant interaction in the average phenanthrene among the pilot conditions and mode combinations.



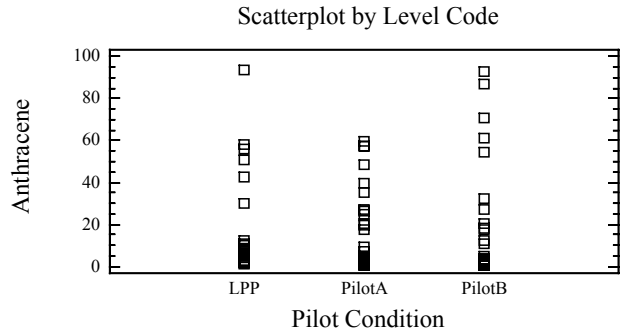
CONCLUSION: There is no significant interaction in the average phenanthrene among the fuel and mode combinations.

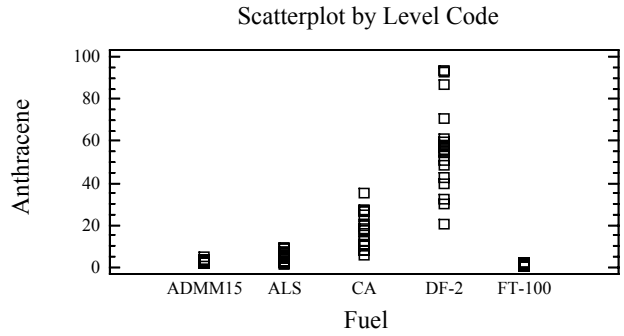
Multifactor ANOVA - Anthracene (micro g/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

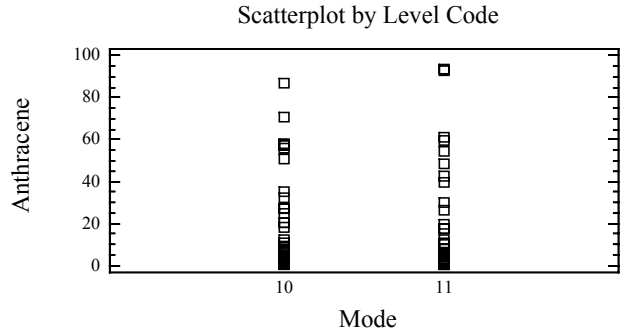
Analysis Summary

Dependent variable: GANTHR
Factors:
COND
FUEL
MODE

Number of complete cases: 91







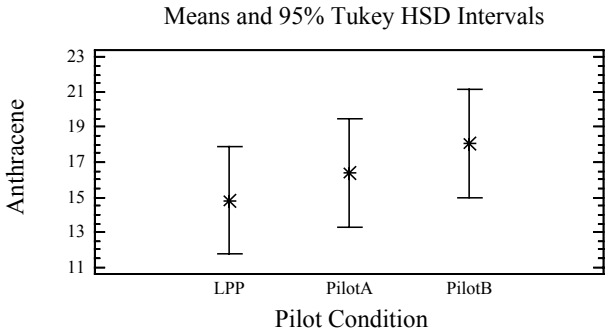
Analysis of Variance for GANTHR - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	160.338	2	80.1692	0.81	0.4497
B:FUEL	38760.6	4	9690.15	97.88	0.0000
C:MODE	24.9234	1	24.9234	0.25	0.6176
INTERACTIONS					

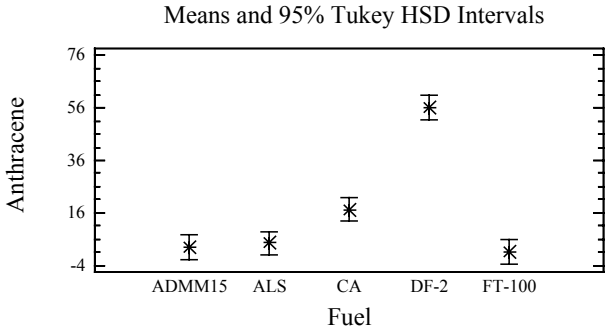
AB	1755.86	8	219.482	2.22	0.0382
AC	4.39302	2	2.19651	0.02	0.9781
BC	209.706	4	52.4265	0.53	0.7144
ABC	73.6331	8	9.20413	0.09	0.9993
RESIDUAL	6038.83	61	98.9973		
TOTAL (CORRECTED)	47005.4	90			

All F-ratios are based on the residual mean square error.

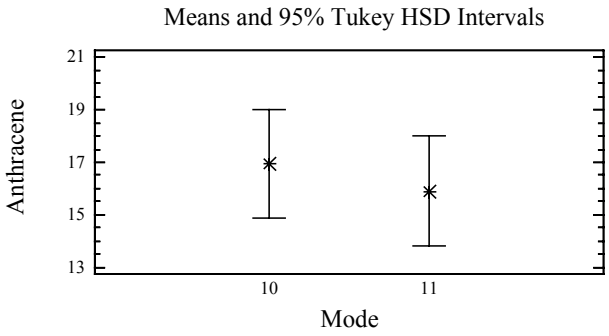
CONCLUSION: Statistically significant differences in the average anthracene among the fuels and pilot condition*fuel interaction.



CONCLUSION: No significant differences in the average anthracene among the three pilot conditions.



CONCLUSION: The average anthracene for the DF-2 and CA fuels is significantly different than the remaining three fuels. The average anthracene for the ADMM15, ALS, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average anthracene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for GANTHR by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	14.8053	X
PilotA	30	16.3714	X
PilotB	30	18.054	X

Contrast	Difference	+/- Limits
LPP - PilotA	-1.56609	6.1218
LPP - PilotB	-3.24865	6.1218
PilotA - PilotB	-1.68256	6.17178

* denotes a statistically significant difference.

Multiple Range Tests for GANTHR by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	1.14399	X
ADMM15	18	2.71767	X
ALS	19	4.56641	X
CA	18	17.3941	X
DF-2	18	56.229	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.84874	9.19969
ADMM15 - CA	*-14.6765	9.32318
ADMM15 - DF-2	*-53.5113	9.32318
ADMM15 - FT-100	1.57367	9.32318
ALS - CA	*-12.8277	9.19969
ALS - DF-2	*-51.6626	9.19969
ALS - FT-100	3.42241	9.19969
CA - DF-2	*-38.8348	9.32318
CA - FT-100	*16.2501	9.32318
DF-2 - FT-100	*55.085	9.32318

* denotes a statistically significant difference.

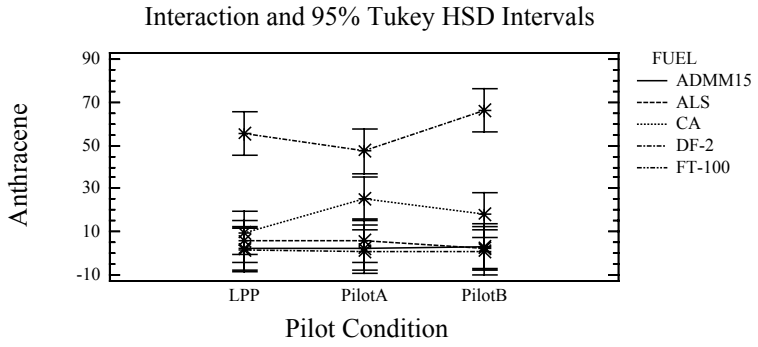
Multiple Range Tests for GANTHR by MODE

Method: 95.0 percent Tukey HSD

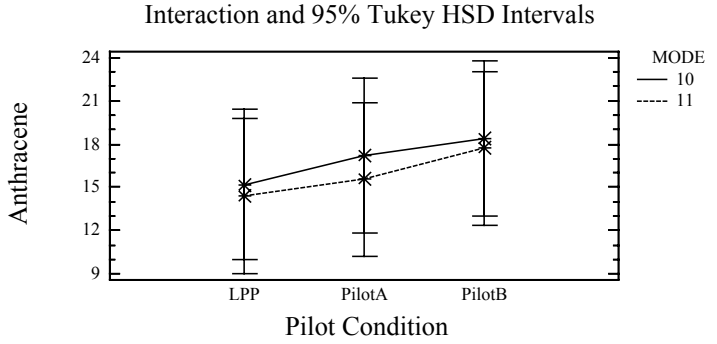
MODE	Count	LS Mean	Homogeneous Groups
11	45	15.8862	X
10	46	16.9343	X

Contrast	Difference	+/- Limits
10 - 11	1.04808	4.17154

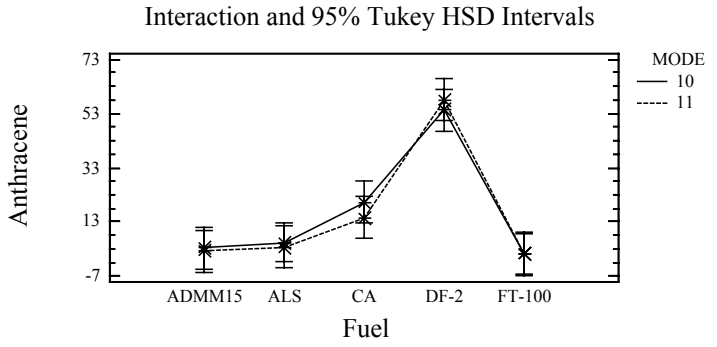
* denotes a statistically significant difference.



CONCLUSION: The trend in the average anthracene across the pilot conditions for the ADMM15, ALS, and FT-100 fuels is significantly different than the trend for the DF-2 and CA fuels. Whereas, the trends in the ADMM15, ALS, and FT-100 fuels are relatively constant, the DF-2 fuel demonstrates a slight increase from the LPP to the Pilot B condition. Also, the CA fuel shows an increase in the Pilot A condition.



CONCLUSION: There is no significant interaction in the average anthracene among the pilot condition and mode combinations.



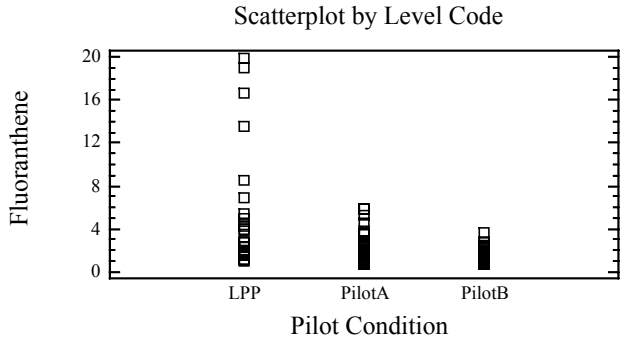
CONCLUSION: There is no significant interaction in the average anthracene among the fuel and mode combinations.

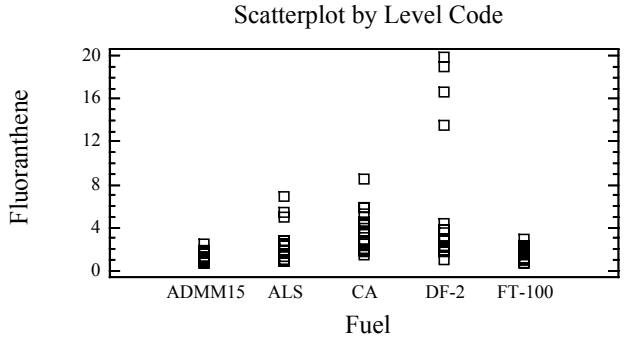
Multifactor ANOVA - Fluoranthene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

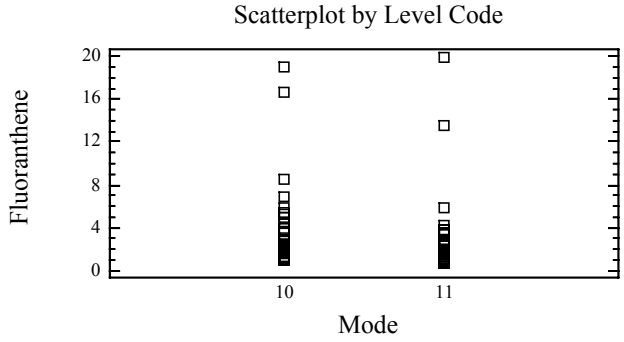
Analysis Summary

Dependent variable: GFLUORAN
Factors:
COND
FUEL
MODE

Number of complete cases: 91







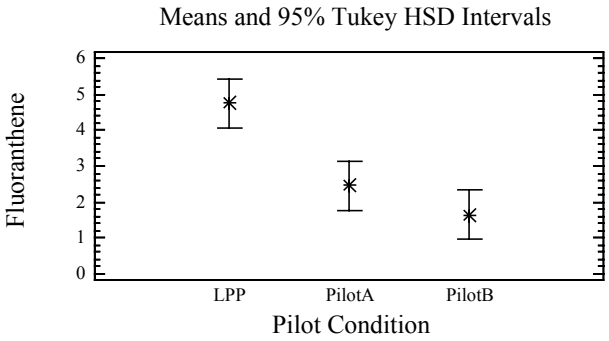
Analysis of Variance for GFLUORAN - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	158.876	2	79.438	15.84	0.0000

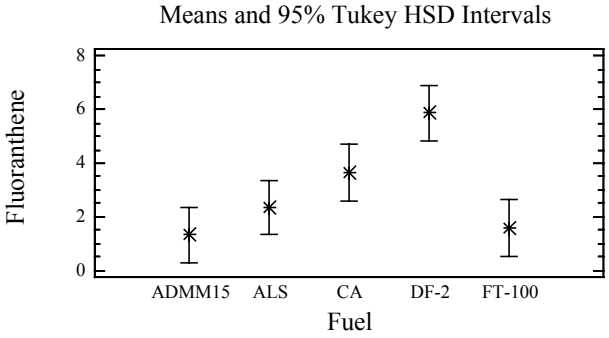
B:FUEL	250.699	4	62.6747	12.50	0.0000
C:MODE	6.45211	1	6.45211	1.29	0.2612
INTERACTIONS					
AB	332.067	8	41.5084	8.28	0.0000
AC	3.93472	2	1.96736	0.39	0.6772
BC	5.44184	4	1.36046	0.27	0.8954
ABC	6.66393	8	0.832991	0.17	0.9946
RESIDUAL	305.959	61	5.01572		
TOTAL (CORRECTED)	1071.07	90			

All F-ratios are based on the residual mean square error.

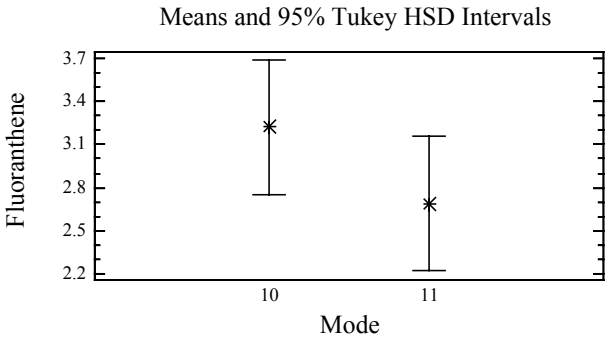
CONCLUSION: Statistically significant differences in the average fluoranthene among the pilot conditions, fuels, and pilot condition*fuel interaction.



CONCLUSION: The average fluoranthene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP conditions.



CONCLUSION: There are several distinct fuel groupings with respect to the average fluoranthene. The average fluoranthene for the DF-2 fuel is significantly different from the remaining four fuels. The CA fuel is significantly different than the ADMM15 fuel, but not significantly different than the ALS or FT-100 fuels.



CONCLUSION: The average fluoranthene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for GFLUORAN by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
PilotB	30	1.64916	X
PilotA	30	2.45675	X
LPP	31	4.76043	X

Contrast	Difference	+/- Limits
LPP - PilotA	*2.30368	1.37795
LPP - PilotB	*3.11127	1.37795
PilotA - PilotB	0.807583	1.3892

* denotes a statistically significant difference.

Multiple Range Tests for GFLUORAN by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	1.31817	X
FT-100	18	1.58958	XX
ALS	19	2.34355	XX
CA	18	3.65466	X
DF-2	18	5.87127	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.02538	2.07075
ADMM15 - CA	*-2.33649	2.09855
ADMM15 - DF-2	*-4.55309	2.09855
ADMM15 - FT-100	-0.271407	2.09855
ALS - CA	-1.31111	2.07075
ALS - DF-2	*-3.52771	2.07075
ALS - FT-100	0.753972	2.07075
CA - DF-2	*-2.21661	2.09855
CA - FT-100	2.06508	2.09855
DF-2 - FT-100	*4.28169	2.09855

* denotes a statistically significant difference.

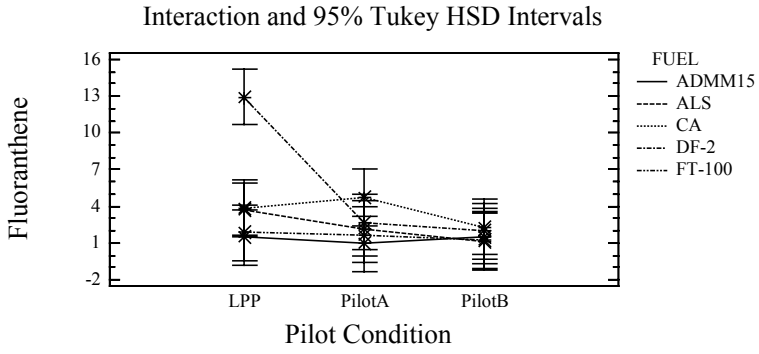
Multiple Range Tests for GFLUORAN by MODE

Method: 95.0 percent Tukey HSD

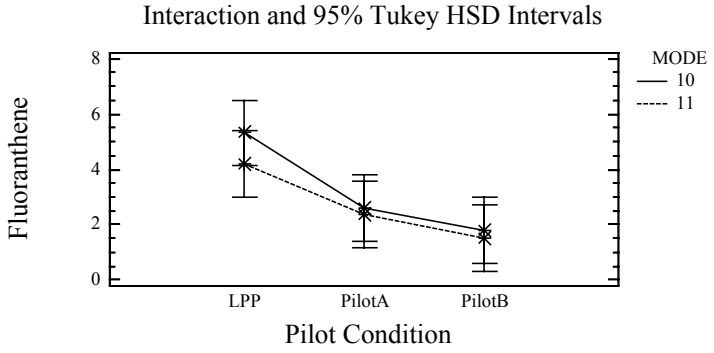
MODE	Count	LS Mean	Homogeneous Groups
11	45	2.68881	X
10	46	3.22208	X

Contrast	Difference	+/- Limits
10 - 11	0.533264	0.938969

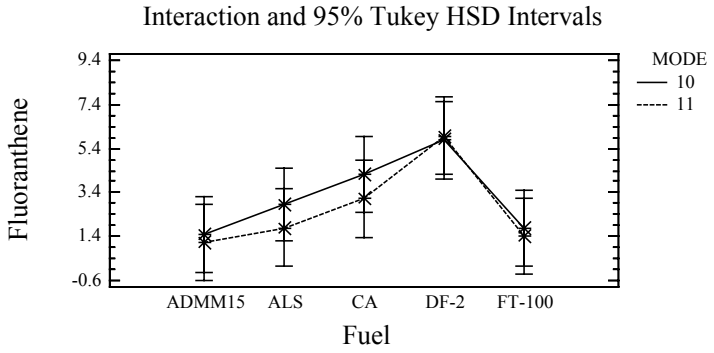
* denotes a statistically significant difference.



CONCLUSION: The trend in the average fluoranthene across the pilot conditions for the ADMM15, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average fluoranthene at the LPP condition.



CONCLUSION: There is no significant interaction in the average fluoranthene among the pilot condition and mode combinations.



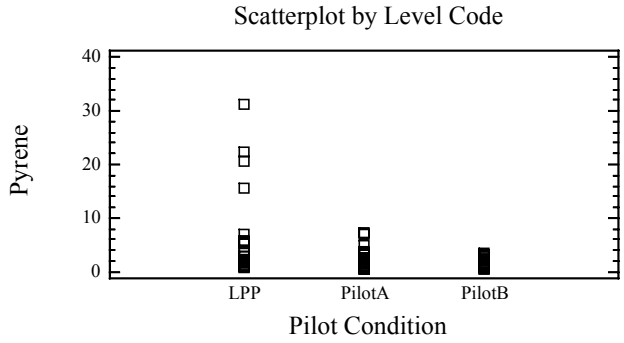
CONCLUSION: There is no significant interaction in the average fluoranthene among the fuel and mode combinations.

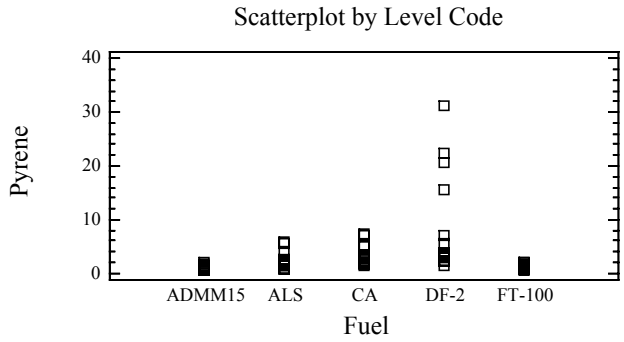
Multifactor ANOVA - Pyrene (µg/kW-hr) Gaseous PAH
Three Pilot Conditions Modes 10 and 11

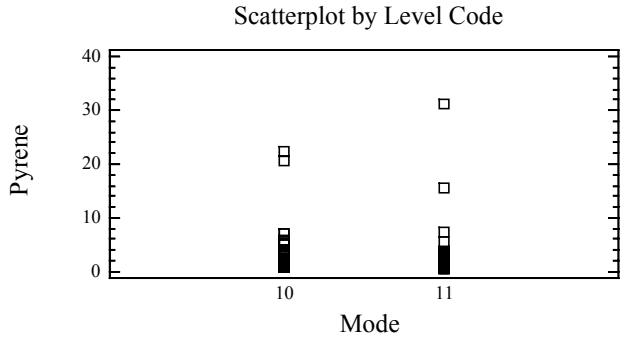
Analysis Summary

Dependent variable: GPYRENE
Factors:
COND
FUEL
MODE

Number of complete cases: 91







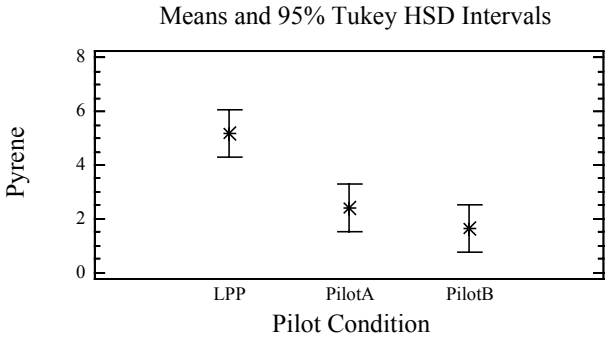
Analysis of Variance for GPYRENE - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	215.921	2	107.961	12.83	0.0000
B:FUEL	522.511	4	130.628	15.52	0.0000
C:MODE	1.64188	1	1.64188	0.20	0.6603

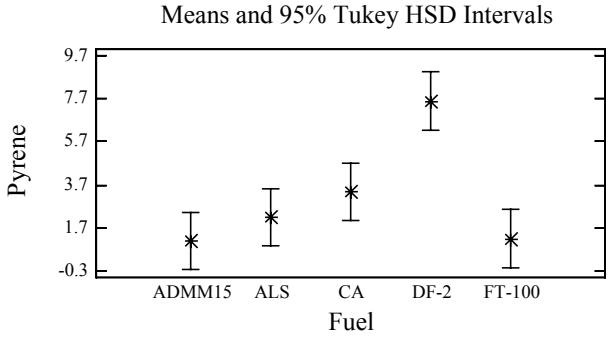
INTERACTIONS					
AB	635.162	8	79.3952	9.43	0.0000
AC	1.44397	2	0.721987	0.09	0.9179
BC	7.72609	4	1.93152	0.23	0.9208
ABC	3.61495	8	0.451869	0.05	0.9999
RESIDUAL	513.495	61	8.41795		
TOTAL (CORRECTED)	1898.24	90			

All F-ratios are based on the residual mean square error.

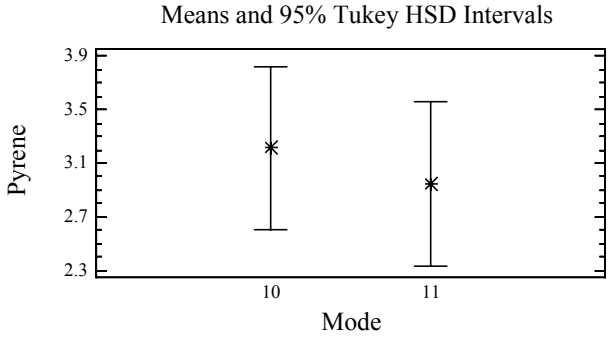
CONCLUSION: Statistically significant differences in the average pyrene among the pilot conditions, fuels, and pilot condition*fuel interaction.



CONCLUSION: The average pyrene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: The average pyrene for the DF-2 fuel is significantly different than the other four fuels. The average pyrene among the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average pyrene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for GPYRENE by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
PilotB	30	1.6312	X
PilotA	30	2.39782	X
LPP	31	5.20555	X

Contrast	Difference	+/- Limits
LPP - PilotA	*2.80773	1.78513
LPP - PilotB	*3.57434	1.78513
PilotA - PilotB	0.766618	1.79971

* denotes a statistically significant difference.

Multiple Range Tests for GPYRENE by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	1.08101	X
FT-100	18	1.1652	X
ALS	19	2.17365	X
CA	18	3.37177	X
DF-2	18	7.59931	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.09263	2.68265
ADMM15 - CA	-2.29075	2.71867
ADMM15 - DF-2	*-6.51829	2.71867
ADMM15 - FT-100	-0.0841837	2.71867
ALS - CA	-1.19812	2.68265
ALS - DF-2	*-5.42566	2.68265
ALS - FT-100	1.00845	2.68265
CA - DF-2	*-4.22754	2.71867
CA - FT-100	2.20657	2.71867
DF-2 - FT-100	*6.43411	2.71867

* denotes a statistically significant difference.

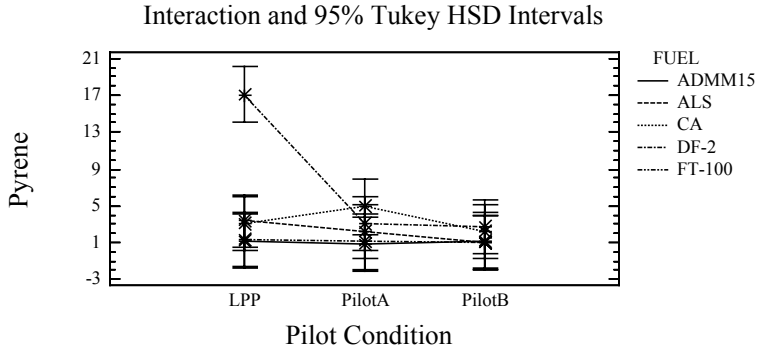
Multiple Range Tests for GPYRENE by MODE

Method: 95.0 percent Tukey HSD

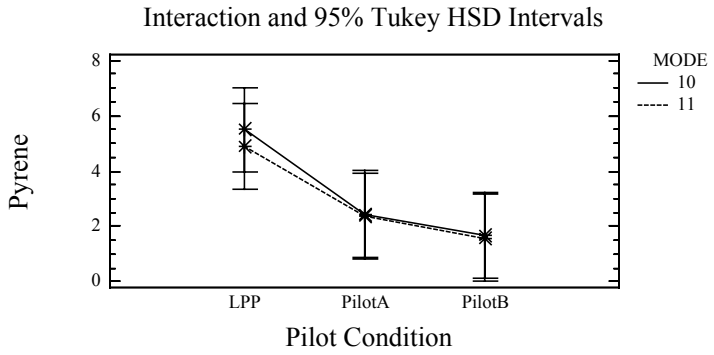
MODE	Count	LS Mean	Homogeneous Groups
11	45	2.94368	X
10	46	3.21269	X

Contrast	Difference	+/- Limits
10 - 11	0.269006	1.21643

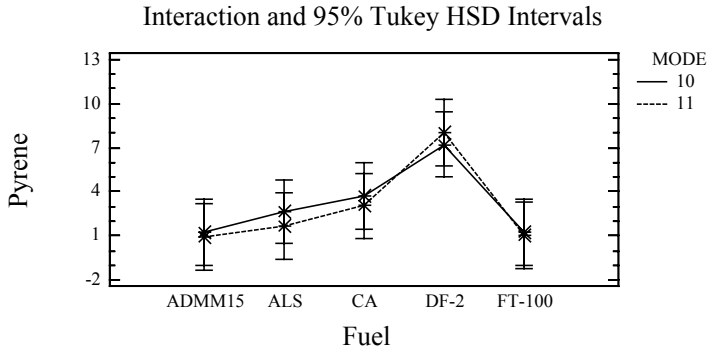
* denotes a statistically significant difference.



CONCLUSION: The trend in the average pyrene across the pilot conditions for the ADMM15, ALS, CA, and FT-100 fuels is significantly different than the trend for the DF-2 fuel. Whereas, the trends in the ADMM15, ALS, CA, and FT-100 fuels are relatively constant, the DF-2 fuel shows an increase in the average pyrene at the LPP condition.



CONCLUSION: There is no significant interaction in the average pyrene among the pilot condition and mode combinations.



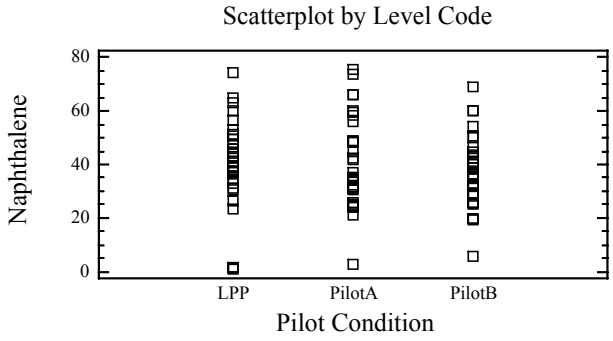
CONCLUSION: There is no significant interaction in the average pyrene among the fuel and mode combinations.

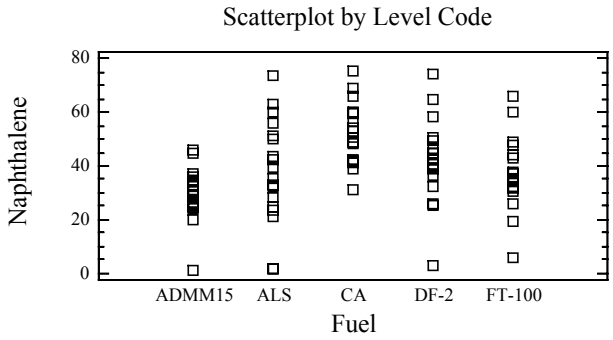
Multifactor ANOVA - Naphthalene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

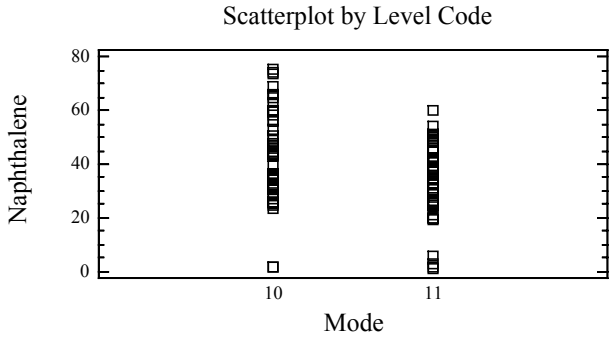
Analysis Summary

Dependent variable: naphth
Factors:
COND
FUEL
MODE

Number of complete cases: 91







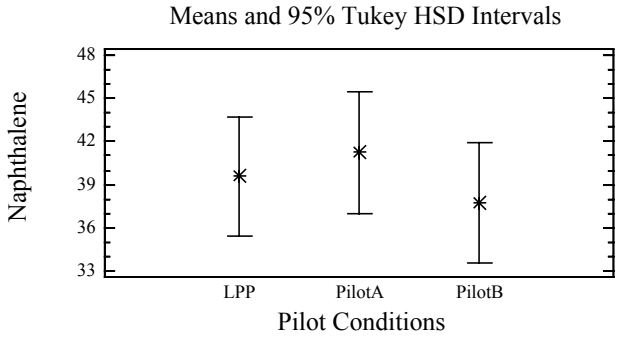
Analysis of Variance for naphth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	183.888	2	91.944	0.49	0.6153
B:FUEL	4980.21	4	1245.05	6.63	0.0002
C:MODE	2252.95	1	2252.95	12.00	0.0010

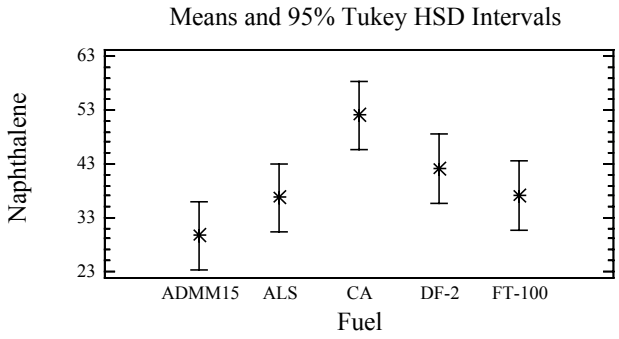
INTERACTIONS					
AB	2923.31	8	365.414	1.95	0.0691
AC	180.828	2	90.4142	0.48	0.6202
BC	830.073	4	207.518	1.10	0.3625
ABC	1268.55	8	158.569	0.84	0.5678
RESIDUAL	11456.5	61	187.812		
TOTAL (CORRECTED)	24216.7	90			

All F-ratios are based on the residual mean square error.

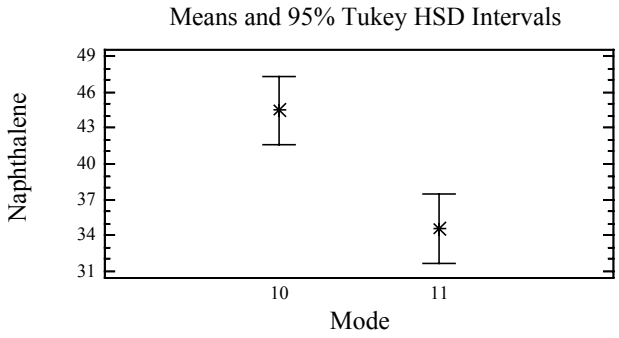
CONCLUSION: Statistically significant differences in the average naphthalene among the fuels and modes.



CONCLUSION: No statistically significant difference in the average naphthalene across the pilot conditions.



CONCLUSION: The average naphthalene for the CA fuel is significantly different from the ADMM15, ALS and FT-100 fuels.



CONCLUSION: The average naphthalene for modes 10 and 11 are significantly different from one another.

Multiple Range Tests for naphth by COND

Method: 95.0 percent Tukey HSD

COND	Count	LS Mean	Homogeneous Groups
PilotB	30	37.731	X
LPP	31	39.5631	X
PilotA	30	41.231	X

Contrast	Difference	+/- Limits
LPP - PilotA	-1.66798	8.43198
LPP - PilotB	1.83203	8.43198
PilotA - PilotB	3.50001	8.50081

* denotes a statistically significant difference.

Multiple Range Tests for naphth by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	29.574	X
ALS	19	36.6896	X
FT-100	18	37.1125	X
DF-2	18	42.1224	XX
CA	18	52.0434	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-7.11555	12.6714
ADMM15 - CA	*-22.4693	12.8415
ADMM15 - DF-2	-12.5483	12.8415
ADMM15 - FT-100	-7.53845	12.8415
ALS - CA	*-15.3538	12.6714
ALS - DF-2	-5.4328	12.6714
ALS - FT-100	-0.422909	12.6714
CA - DF-2	9.92098	12.8415
CA - FT-100	*14.9309	12.8415
DF-2 - FT-100	5.00989	12.8415

* denotes a statistically significant difference.

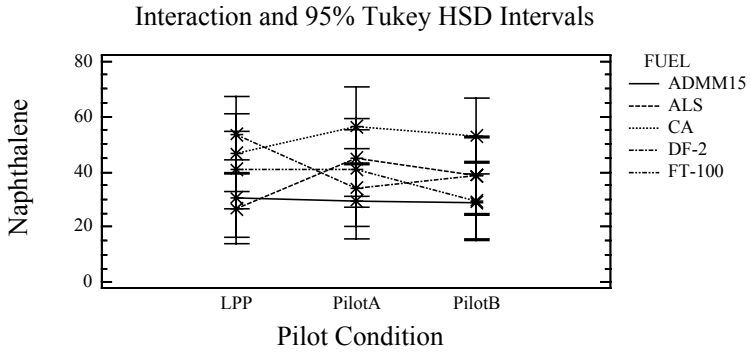
Multiple Range Tests for naphth by MODE

Method: 95.0 percent Tukey HSD

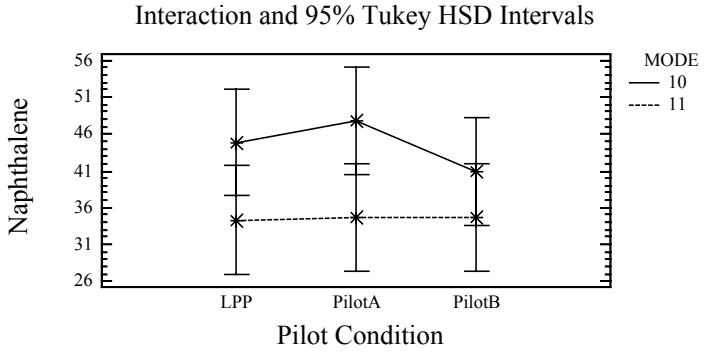
MODE	Count	LS Mean	Homogeneous Groups
11	45	34.526	X
10	46	44.4908	X

Contrast	Difference	+/- Limits
10 - 11	*9.96478	5.74574

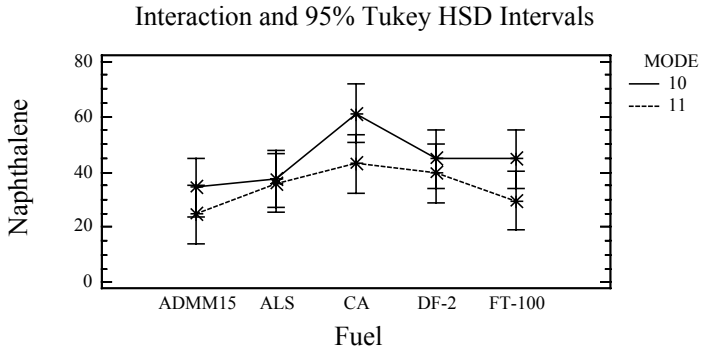
* denotes a statistically significant difference.



CONCLUSION: There is no significant interaction in the average naphthalene among the fuel and pilot condition combinations.



CONCLUSION: There is no significant interaction in the average naphthalene among the mode and pilot condition combinations.



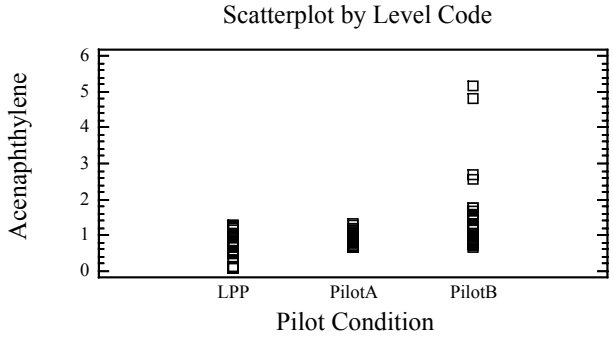
CONCLUSION: There is no significant interaction in the average naphthalene among the mode and fuel combinations.

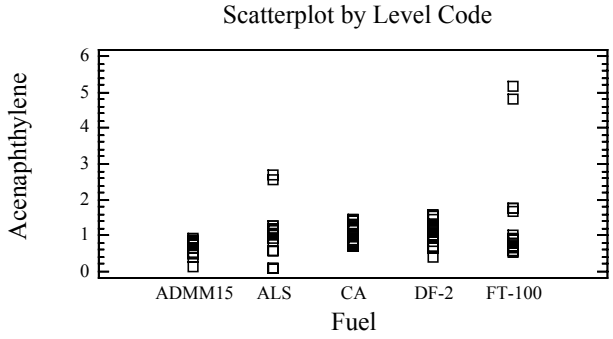
Multifactor ANOVA - Acenaphthylene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

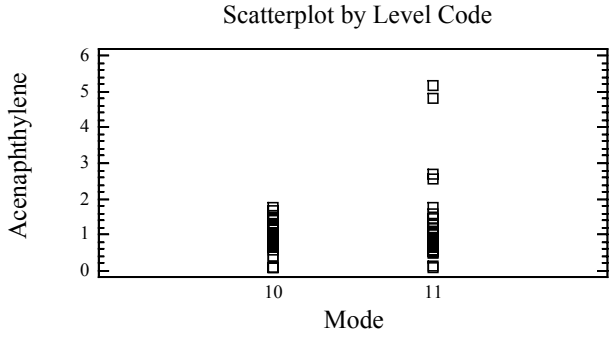
Analysis Summary

Dependent variable: acenaph
Factors:
COND
FUEL
MODE

Number of complete cases: 91







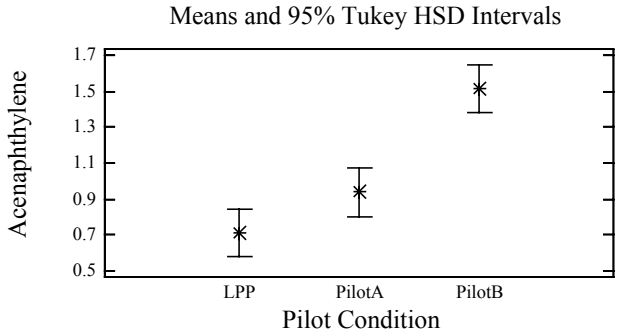
Analysis of Variance for acenaph - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	10.4983	2	5.24915	28.01	0.0000
B:FUEL	4.52142	4	1.13036	6.03	0.0004
C:MODE	0.345356	1	0.345356	1.84	0.1796

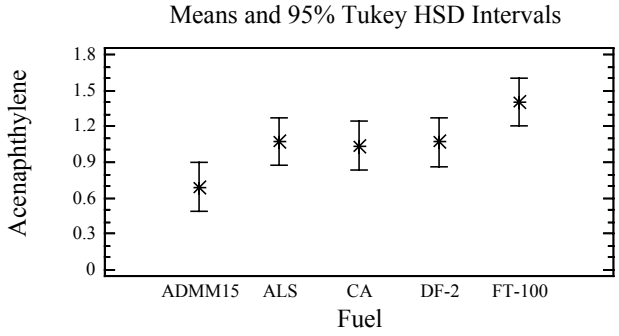
INTERACTIONS					
AB	9.86361	8	1.23295	6.58	0.0000
AC	2.57901	2	1.2895	6.88	0.0020
BC	4.03223	4	1.00806	5.38	0.0009
ABC	4.73901	8	0.592376	3.16	0.0046
RESIDUAL	11.4328	61	0.187423		
TOTAL (CORRECTED)	48.2402	90			

All F-ratios are based on the residual mean square error.

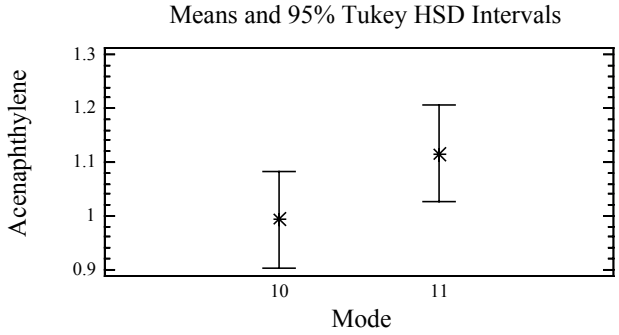
CONCLUSION: Statistically significant differences in the average acenaphthylene among the pilot conditions, fuels, two-factor interactions, and the three-factor interaction fuel*mode*pilot condition.



CONCLUSION: The average acenaphthylene for the LPP and Pilot A conditions are not significantly different from one another, but are significantly different from the Pilot B condition.



CONCLUSION: The average acenaphthylene for the ADMM15 fuel is significantly different from the FT-100 fuel. The CA, DF-2, and ALS fuels are not significantly different from either the ADMM15 or the FT-100 fuels with respect to the average acenaphthylene.



CONCLUSION: The average acenaphthylene for modes 10 and 11 are not significantly different from one another.

Multiple Range Tests for acenaph by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	0.709427	X
PilotA	30	0.936941	X
PilotB	30	1.51712	X

Contrast	Difference	+/- Limits
LPP - PilotA	-0.227514	0.266366
LPP - PilotB	*-0.807697	0.266366
PilotA - PilotB	*-0.580183	0.268541

* denotes a statistically significant difference.

Multiple Range Tests for acenaph by FUEL

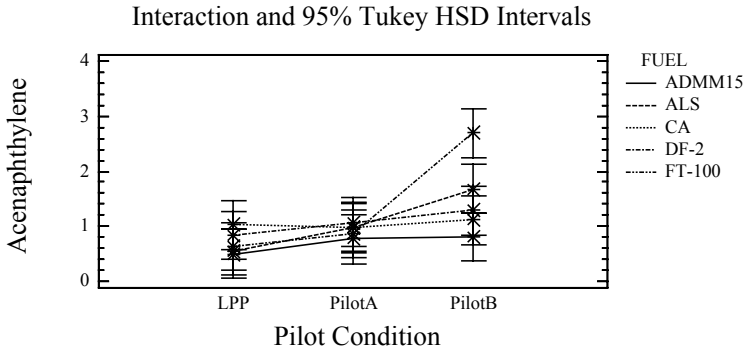
Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	0.693977	X
CA	18	1.03841	XX
DF-2	18	1.06802	XX
ALS	19	1.07044	XX
FT-100	18	1.40164	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.376466	0.400288
ADMM15 - CA	-0.344432	0.405662
ADMM15 - DF-2	-0.374041	0.405662
ADMM15 - FT-100	*-0.707664	0.405662
ALS - CA	0.0320337	0.400288
ALS - DF-2	0.00242547	0.400288
ALS - FT-100	-0.331198	0.400288
CA - DF-2	-0.0296082	0.405662
CA - FT-100	-0.363231	0.405662
DF-2 - FT-100	-0.333623	0.405662

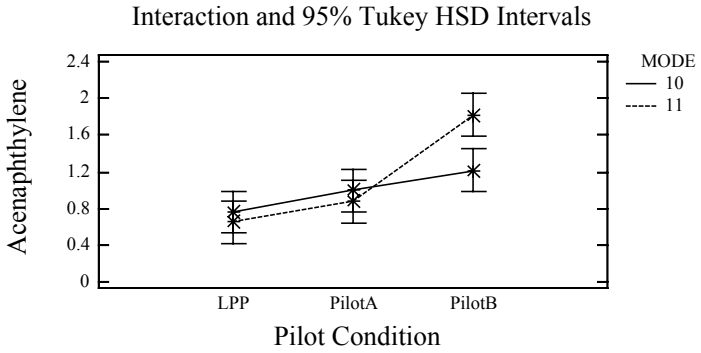
* denotes a statistically significant difference.

Multiple Range Tests for acenaph by MODE

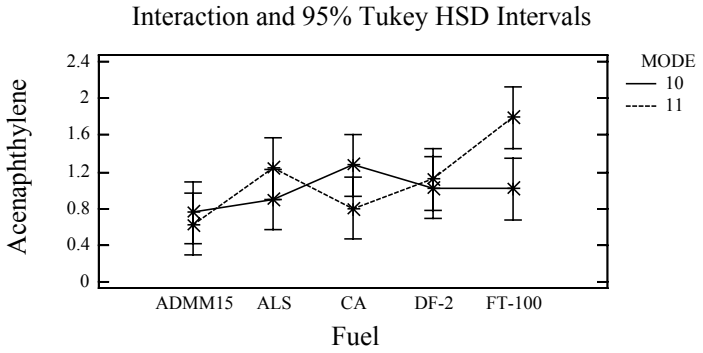
```
------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
MODE           Count     LS Mean           Homogeneous Groups
------------------------------------------------------------------------------
10             46        0.99281           X
11             45        1.11618           X
------------------------------------------------------------------------------
Contrast                                 Difference           +/-  Limits
------------------------------------------------------------------------------
10 - 11                                  -0.123374            0.181508
------------------------------------------------------------------------------
* denotes a statistically significant difference.
```



CONCLUSION: The trend in the average acenaphthylene across the pilot conditions for the FT-100 fuel is significantly different than the trends for the remaining four fuels. The average acenaphthylene for the FT-100 fuel at the Pilot B condition is significantly different than the other four fuels, but not at the LPP or the Pilot A condition.



CONCLUSION: The average acenaphthylene at the Pilot B condition for Mode 11 is significantly different than Mode 10. There is no significant difference in the average acenaphthylene between the two modes at the LPP or Pilot A conditions.



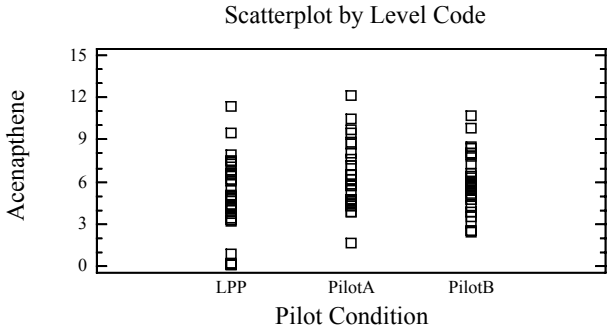
CONCLUSION: The trend in the average acenaphthylene across the two modes is different at the FT-100 fuel. There does not appear to be differences in the average acenaphthylene for the two modes at the ADMM15, ALS, CA, or DF-2 fuels.

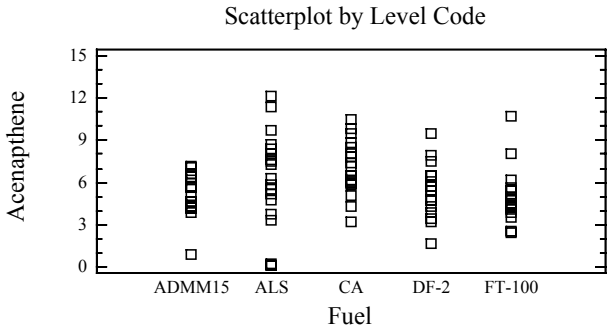
Multifactor ANOVA - Acenaphthene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modees 10 and 11

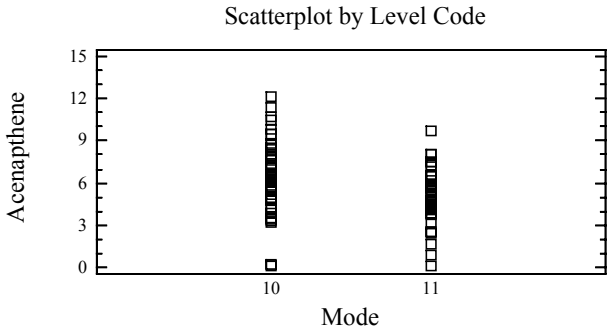
Analysis Summary

Dependent variable: acenapth
Factors:
COND
FUEL
MODE

Number of complete cases: 91







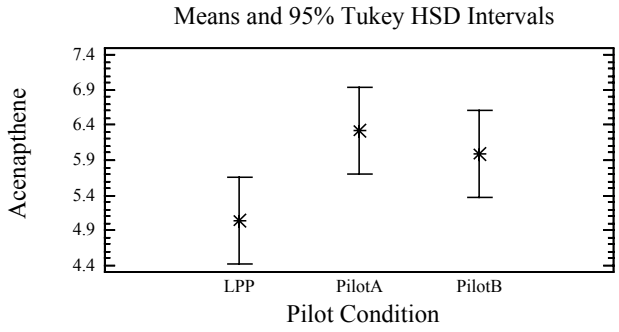
Analysis of Variance for acenapth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	26.9198	2	13.4599	3.31	0.0431
B:FUEL	53.0297	4	13.2574	3.26	0.0172
C:MODE	47.9888	1	47.9888	11.81	0.0011

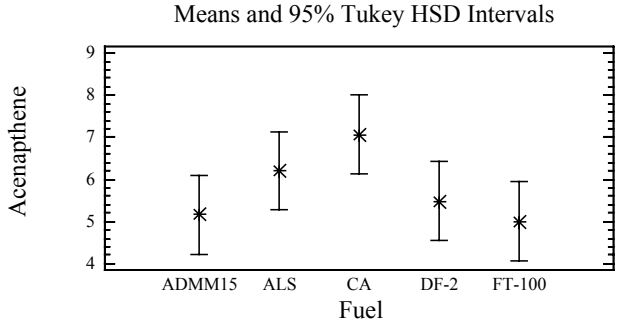
INTERACTIONS					
AB	89.368	8	11.171	2.75	0.0117
AC	4.11053	2	2.05526	0.51	0.6056
BC	15.9586	4	3.98965	0.98	0.4243
ABC	12.8542	8	1.60677	0.40	0.9189
RESIDUAL	247.905	61	4.06401		
TOTAL (CORRECTED)	498.837	90			

All F-ratios are based on the residual mean square error.

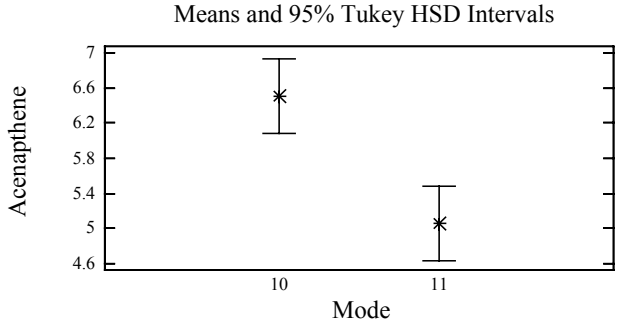
CONCLUSION: Statistically significant differences in the average acenaphthene among the pilot conditions, fuels, modes, and pilot condition*fuel interaction.



CONCLUSION: The average acenaphthene for the LPP condition is significantly different than the Pilot A condition. The average acenaphthene for the Pilot B condition is not significantly different from with either the LPP or the Pilot A conditions.



CONCLUSION: The average acenaphthene for the CA fuel is significantly different from the ADMM15 and the FT-100 fuels.



CONCLUSION: The average acenaphthene for modes 10 and 11 are significantly

different from one another.

Multiple Range Tests for acenapth by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	5.03969	X
PilotB	30	5.98379	XX
PilotA	30	6.32198	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-1.28229	1.24035
LPP - PilotB	-0.944107	1.24035
PilotA - PilotB	0.338184	1.25048

* denotes a statistically significant difference.

Multiple Range Tests for acenapth by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	4.99828	X
ADMM15	18	5.15909	X
DF-2	18	5.47325	XX
ALS	19	6.20856	XX
CA	18	7.06992	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.04948	1.86397
ADMM15 - CA	*-1.91083	1.88899
ADMM15 - DF-2	-0.314163	1.88899
ADMM15 - FT-100	0.160804	1.88899
ALS - CA	-0.86135	1.86397
ALS - DF-2	0.735315	1.86397
ALS - FT-100	1.21028	1.86397
CA - DF-2	1.59667	1.88899
CA - FT-100	*2.07163	1.88899
DF-2 - FT-100	0.474967	1.88899

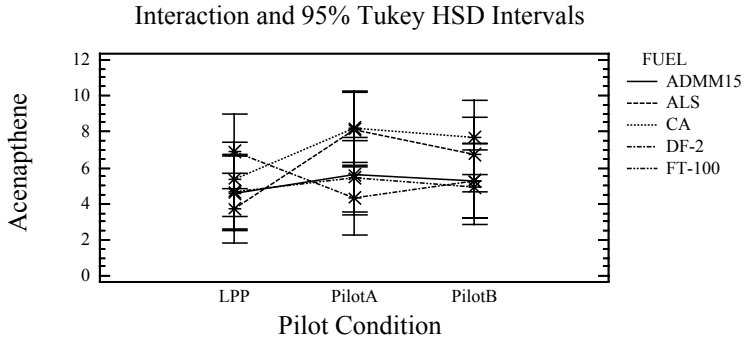
* denotes a statistically significant difference.

Multiple Range Tests for acenapth by MODE

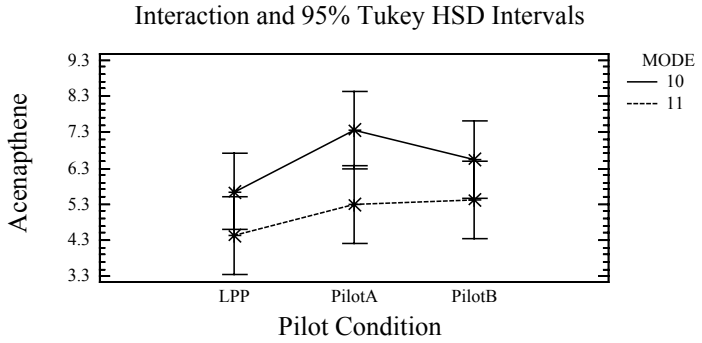
Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
11	45	5.05466	X
10	46	6.50898	X

Contrast	Difference	+/- Limits
10 - 11	*1.45433	0.845205

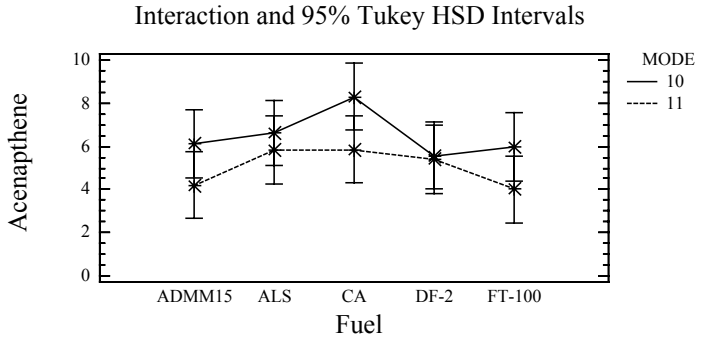
* denotes a statistically significant difference.



CONCLUSION: The trends in the average acenaphthene for the ALS and CA fuels are significantly different than the DF-2 fuel between the LPP and Pilot A conditions.



CONCLUSION: There is no significant interaction in the average acenaphthene among the pilot condition and mode combinations.



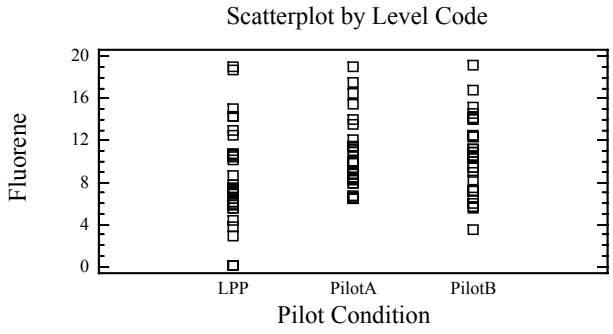
CONCLUSION: There is no significant interaction in the average acenaphthene among the fuel and mode combinations.

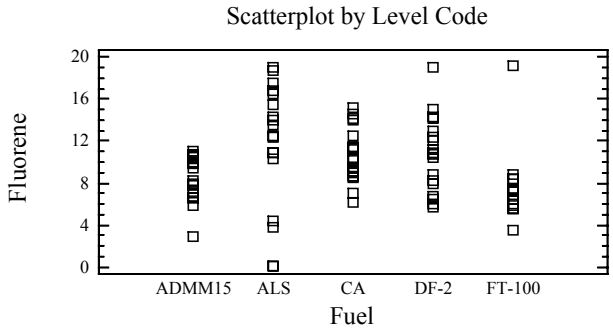
Multifactor ANOVA - Fluorene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

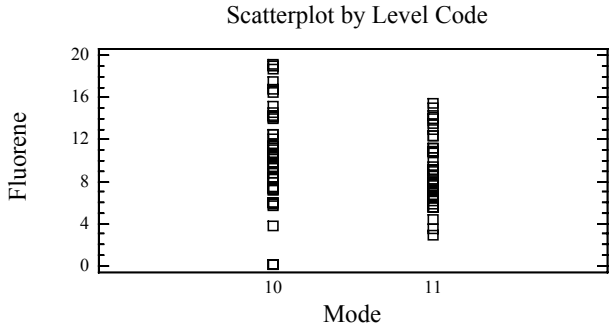
Analysis Summary

Dependent variable: fluorene
Factors:
COND
FUEL
MODE

Number of complete cases: 90







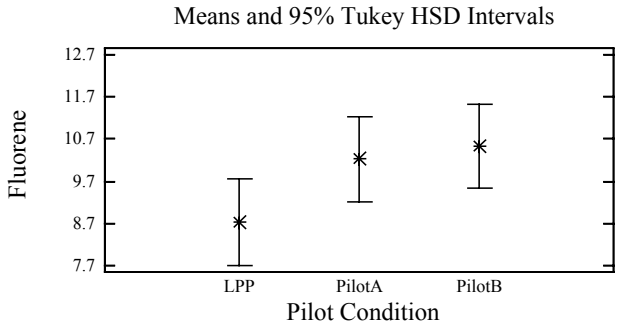
Analysis of Variance for fluorene - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	55.271	2	27.6355	2.62	0.0808
B:FUEL	243.792	4	60.9481	5.79	0.0005
C:MODE	101.916	1	101.916	9.68	0.0029

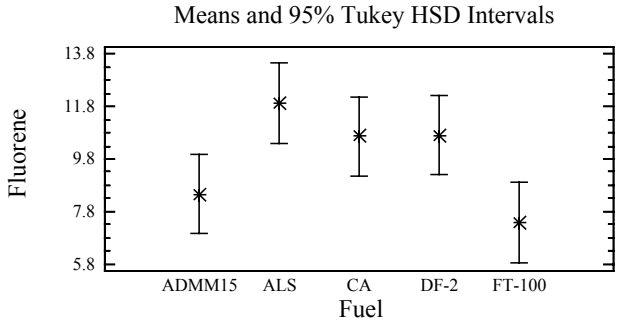
INTERACTIONS					
AB	244.985	8	30.6231	2.91	0.0083
AC	13.768	2	6.88402	0.65	0.5237
BC	43.3634	4	10.8409	1.03	0.3995
ABC	59.6242	8	7.45303	0.71	0.6834
RESIDUAL	631.743	60	10.5291		
TOTAL (CORRECTED)	1426.28	89			

All F-ratios are based on the residual mean square error.

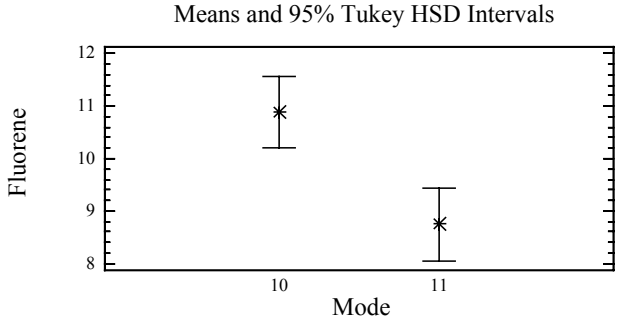
CONCLUSION: Statistically significant differences in the average fluorene among the fuels, modes, and pilot condition*fuel interaction.



CONCLUSION: No significant differences in the average fluorene among the pilot conditions.



CONCLUSION: The average fluorene for the ALS, CA, and DF-2 fuels are significantly different from the FT-100 fuel, but not significantly different from one another. Also, the average fluorene for the ALS fuel is signficantly different from the ADMM15 fuel.



CONCLUSION: The average fluorene for modes 10 and 11 are significantly different from one another,

Multiple Range Tests for fluorene by COND

Method: 95.0 percent Tukey HSD

COND	Count	LS Mean	Homogeneous Groups
LPP	30	8.72343	X
PilotA	30	10.2222	X
PilotB	30	10.5328	X

Contrast	Difference	+/- Limits
LPP - PilotA	-1.4988	2.01361
LPP - PilotB	-1.8094	2.01361
PilotA - PilotB	-0.310597	2.01361

* denotes a statistically significant difference.

Multiple Range Tests for fluorene by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	7.3756	X
ADMM15	18	8.46579	XX
CA	18	10.6592	XX
DF-2	18	10.7079	XX
ALS	18	11.9224	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-3.45656	3.04205
ADMM15 - CA	-2.19339	3.04205
ADMM15 - DF-2	-2.24208	3.04205
ADMM15 - FT-100	1.09019	3.04205
ALS - CA	1.26317	3.04205
ALS - DF-2	1.21448	3.04205
ALS - FT-100	*4.54675	3.04205
CA - DF-2	-0.0486894	3.04205
CA - FT-100	*3.28358	3.04205
DF-2 - FT-100	*3.33227	3.04205

* denotes a statistically significant difference.

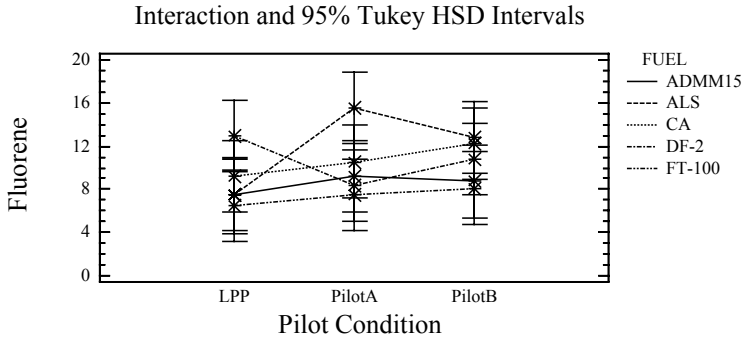
Multiple Range Tests for fluorene by MODE

Method: 95.0 percent Tukey HSD

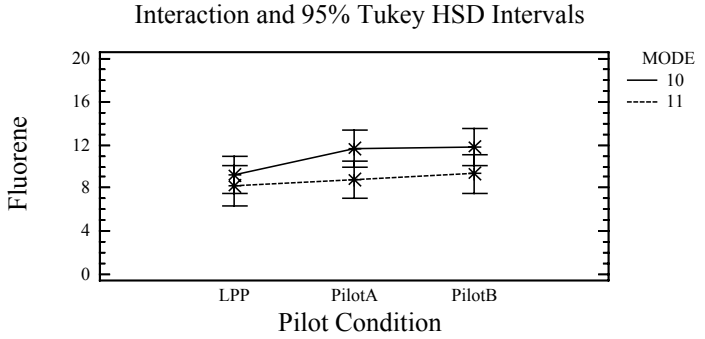
MODE	Count	LS Mean	Homogeneous Groups
11	44	8.75759	X
10	46	10.8947	X

Contrast	Difference	+/- Limits
10 - 11	*2.13714	1.36869

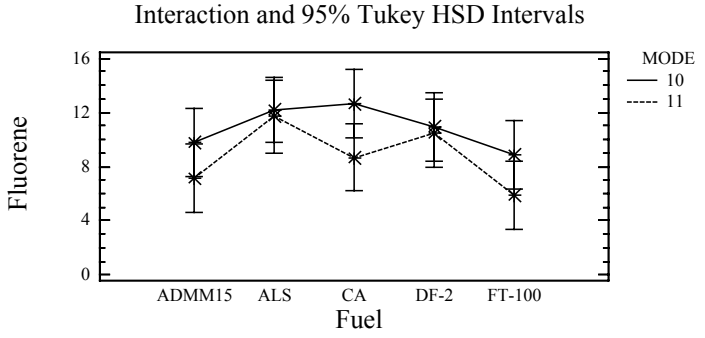
* denotes a statistically significant difference.



CONCLUSION: The trend in the average fluorene for the DF-2 fuel is significantly different than the ALS fuel between the LPP and Pilot A conditions. The CA, ADMM15, and FT-100 fuels demonstrate similar trends across the pilot conditions with respect to the average fluorene.



CONCLUSION: There is no significant interaction in the average fluorene among the pilot condition and mode combinations.



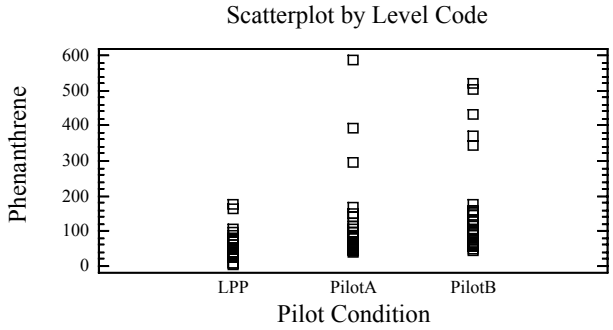
CONCLUSION: There is no significant interaction in the average fluorene among the fuel and mode combinations.

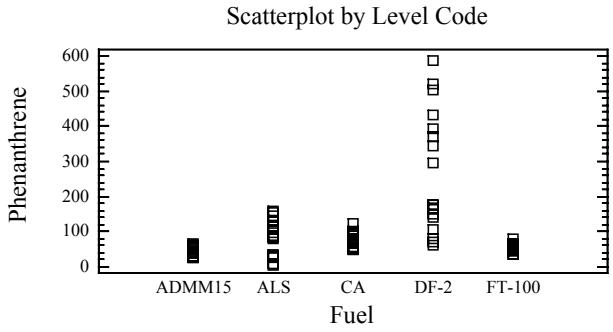
Multifactor ANOVA - Phenanthrene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

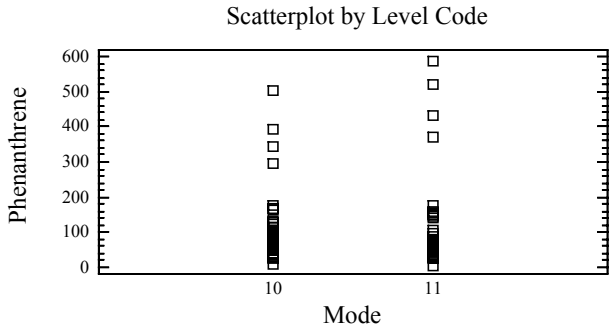
Analysis Summary

Dependent variable: phenanth
Factors:
COND
FUEL
MODE

Number of complete cases: 91







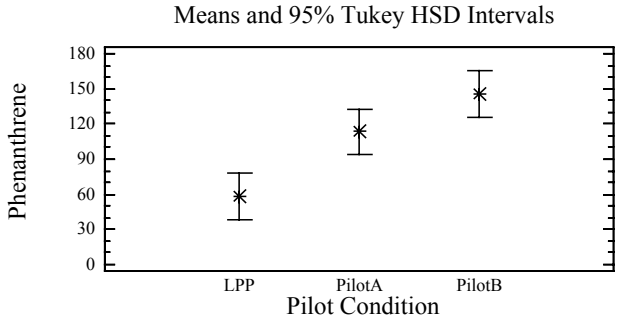
Analysis of Variance for phenanth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	119680.0	2	59840.1	14.87	0.0000
B:FUEL	578014.0	4	144504.0	35.92	0.0000
C:MODE	20.9487	1	20.9487	0.01	0.9427

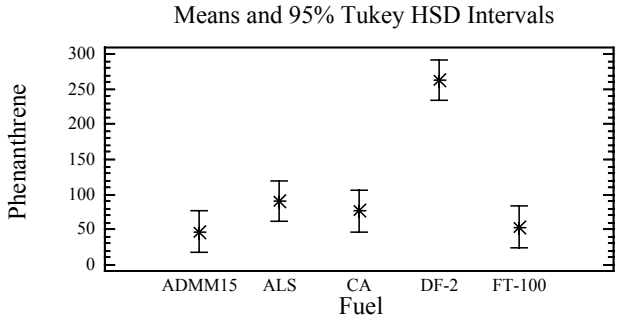
INTERACTIONS					
AB	162582.0	8	20322.8	5.05	0.0001
AC	3706.27	2	1853.13	0.46	0.6331
BC	10391.8	4	2597.96	0.65	0.6320
ABC	7932.45	8	991.556	0.25	0.9799
RESIDUAL	245398.0	61	4022.92		
TOTAL (CORRECTED)	1.13031E6	90			

All F-ratios are based on the residual mean square error.

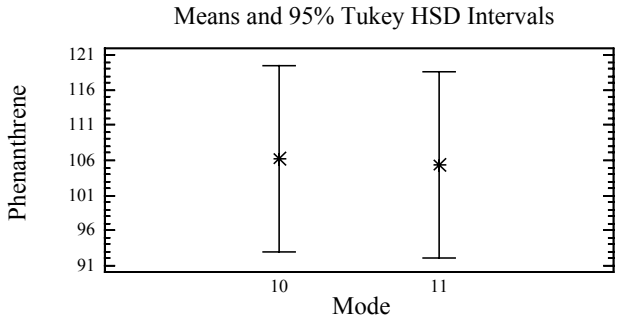
CONCLUSION: Statistically significant differences in the average phenanthrene among the pilot conditions, fuels, and pilot condition*fuel interaction.



CONCLUSION: The average phenanthrene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: The average phenanthrene for the DF-2 fuel is significantly different than the remaining four fuels. The average phenanthrene for the ADMM15, FT-100, Ca, and ALS fuels are not significantly different from one another.



CONCLUSION: There is no significant difference in the average phenanthrene among the two modes.

Multiple Range Tests for phenanth by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	58.1416	X
PilotA	30	113.44	X
PilotB	30	145.824	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-55.2985	39.0246
LPP - PilotB	*-87.6821	39.0246
PilotA - PilotB	-32.3835	39.3432

* denotes a statistically significant difference.

Multiple Range Tests for phenanth by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	46.4785	X
FT-100	18	52.9229	X
CA	18	75.9431	X
ALS	19	90.7957	X
DF-2	18	262.869	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-44.3172	58.6452
ADMM15 - CA	-29.4646	59.4324
ADMM15 - DF-2	*-216.39	59.4324
ADMM15 - FT-100	-6.44444	59.4324
ALS - CA	14.8526	58.6452
ALS - DF-2	*-172.073	58.6452
ALS - FT-100	37.8727	58.6452
CA - DF-2	*-186.926	59.4324
CA - FT-100	23.0202	59.4324
DF-2 - FT-100	*209.946	59.4324

* denotes a statistically significant difference.

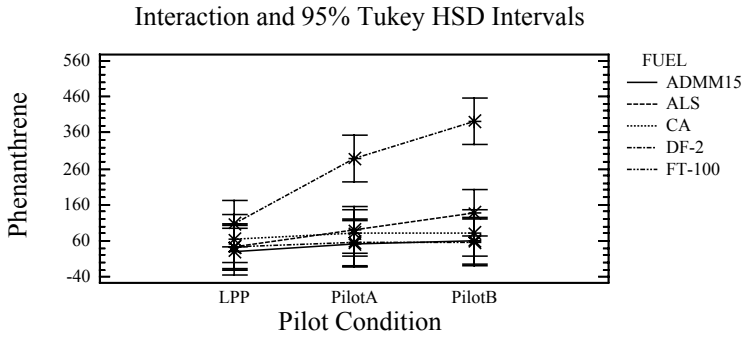
Multiple Range Tests for phenanth by MODE

Method: 95.0 percent Tukey HSD

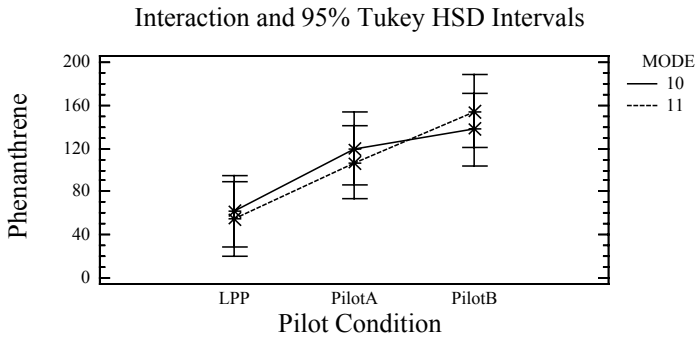
MODE	Count	LS Mean	Homogeneous Groups
11	45	105.321	X
10	46	106.282	X

Contrast	Difference	+/- Limits
10 - 11	0.960882	26.5923

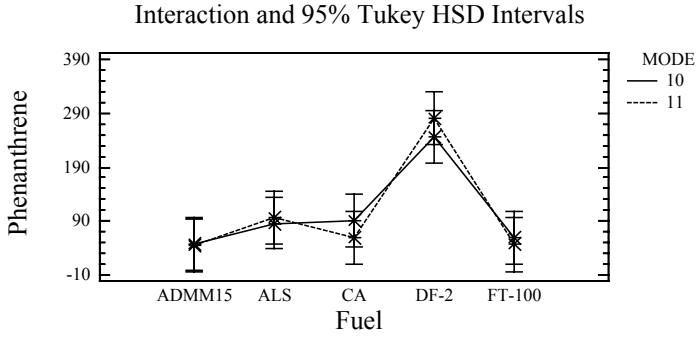
* denotes a statistically significant difference.



CONCLUSION: The trend in the average phenanthrene across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average phenanthrene for the DF-2 fuel at the Pilot A and Pilot B conditions are significantly different than the other four fuels.



CONCLUSION: There is no significant interaction in the average phenanthrene among the pilot condition and mode combinations.



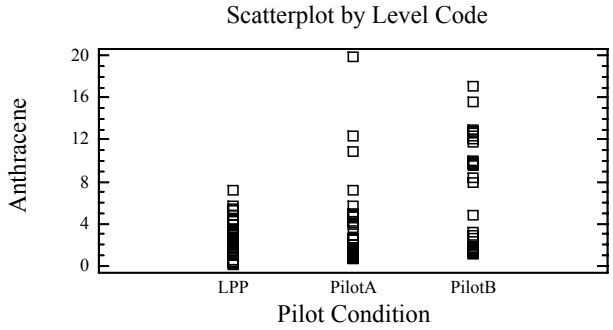
CONCLUSION: There is no significant interaction in the average phenanthrene among the fuel and mode combinations.

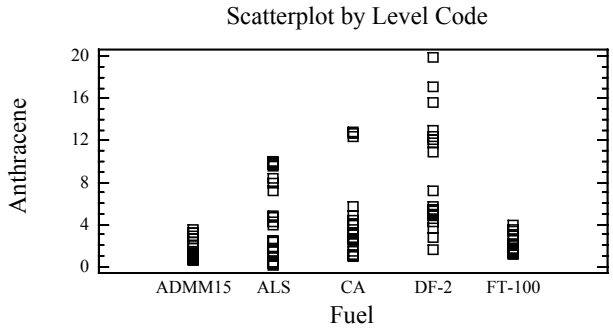
Multifactor ANOVA - Anthracene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

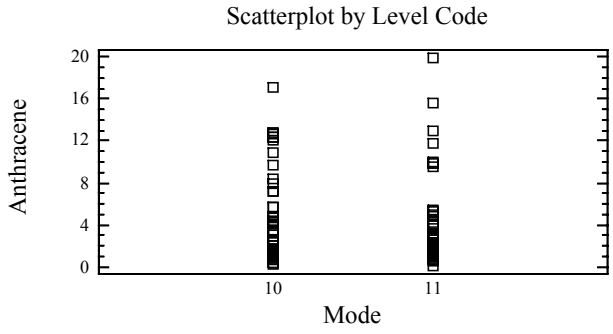
Analysis Summary

Dependent variable: anthr
Factors:
COND
FUEL
MODE

Number of complete cases: 91







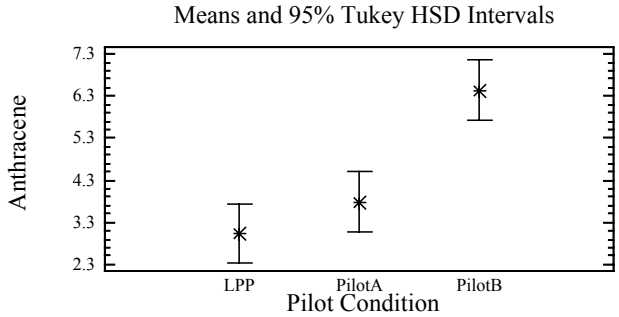
Analysis of Variance for anthr - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	194.971	2	97.4855	18.66	0.0000
B:FUEL	578.264	4	144.566	27.67	0.0000
C:MODE	14.2719	1	14.2719	2.73	0.1035

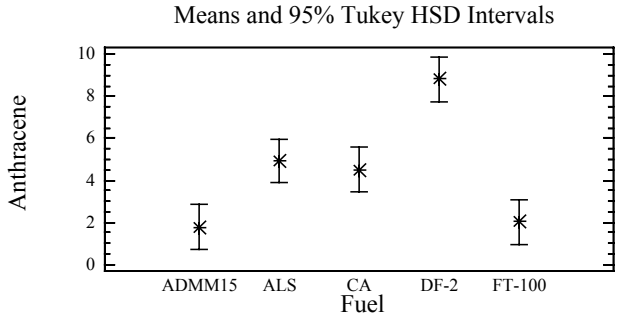
INTERACTIONS					
AB	292.709	8	36.5887	7.00	0.0000
AC	2.55918	2	1.27959	0.24	0.7835
BC	89.3981	4	22.3495	4.28	0.0041
ABC	102.962	8	12.8702	2.46	0.0221
RESIDUAL	318.721	61	5.22494		
TOTAL (CORRECTED)	1599.78	90			

All F-ratios are based on the residual mean square error.

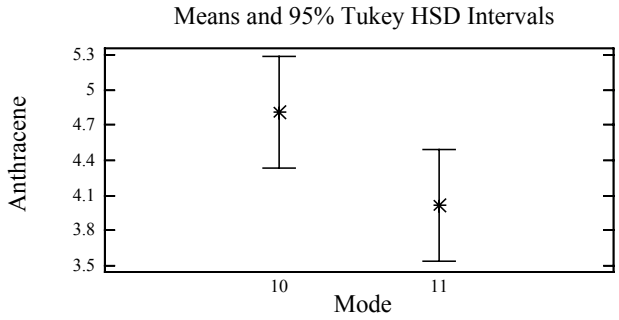
CONCLUSION: Statistically significant differences in the average anthracene among the pilot conditions, fuels, pilot condition*fuel interaction, fuel*mode interaction, and the three-factor interaction.



CONCLUSION: The average anthracene for the LPP and Pilot A conditions are not significantly different from one another, but are significantly different from the Pilot B condition.



CONCLUSION: There are three distinct fuel groupings with respect to the average anthracene. The average anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The ADMM15 and FT-100 fuels are not significantly different from one another, but are signficantly different than the remaining three fuels. Also, the CA and ALS fuels are not significantly different from one another, but are significantly different from the remaining fuels.



CONCLUSION: There is no significant difference in the average anthracene among the two modes.

Multiple Range Tests for anthr by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	3.02166	X
PilotA	30	3.77928	X
PilotB	30	6.44088	X

Contrast	Difference	+/- Limits
LPP - PilotA	-0.75762	1.4064
LPP - PilotB	*-3.41923	1.4064
PilotA - PilotB	*-2.66161	1.41788

* denotes a statistically significant difference.

Multiple Range Tests for anthr by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	1.77706	X
FT-100	18	2.04042	X
CA	18	4.50814	X
ALS	19	4.94414	X
DF-2	18	8.79993	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-3.16708	2.1135
ADMM15 - CA	*-2.73109	2.14187
ADMM15 - DF-2	*-7.02287	2.14187
ADMM15 - FT-100	-0.263363	2.14187
ALS - CA	0.435995	2.1135
ALS - DF-2	*-3.85579	2.1135
ALS - FT-100	*2.90372	2.1135
CA - DF-2	*-4.29179	2.14187
CA - FT-100	*2.46772	2.14187
DF-2 - FT-100	*6.75951	2.14187

* denotes a statistically significant difference.

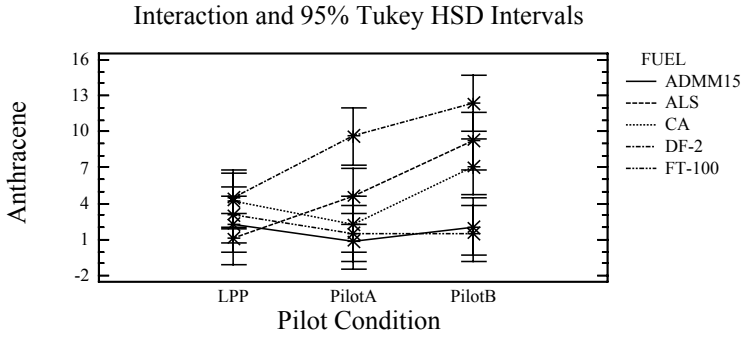
Multiple Range Tests for anthr by MODE

Method: 95.0 percent Tukey HSD

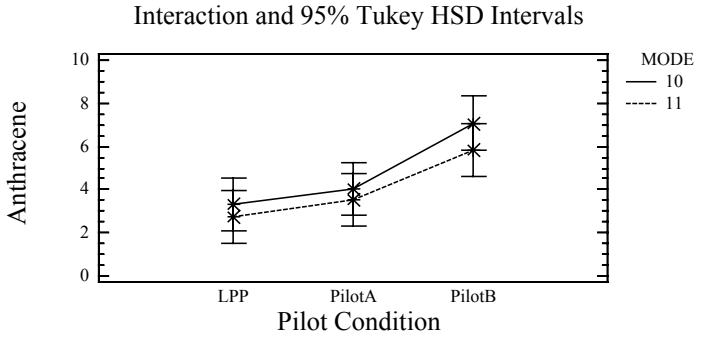
MODE	Count	LS Mean	Homogeneous Groups
11	45	4.01738	X
10	46	4.81049	X

Contrast	Difference	+/- Limits
10 - 11	0.793108	0.958353

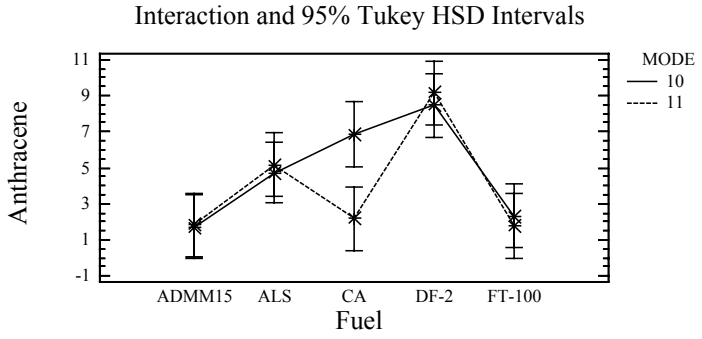
* denotes a statistically significant difference.



CONCLUSION: The trends in the average anthracene across the pilot conditions for the DF-2 and ALS fuels are significantly different than the trends for the remaining three fuels. The average anthracene for the DF-2 fuel at the Pilot A and Pilot B conditions are significantly different than the CA, FT-100, and ADMM15 fuels.



CONCLUSION: There is no significant interaction in the average anthracene among the pilot condition and mode combinations.



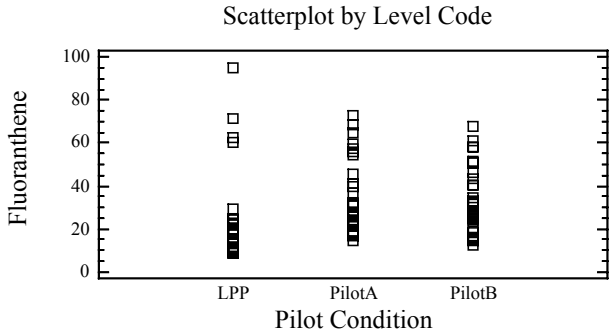
CONCLUSION: The trends in the average anthracene for modes 10 and 11 are significantly different at the CA fuel. Otherwise, the average anthracene for the two modes are not significantly different across the remaining four fuels.

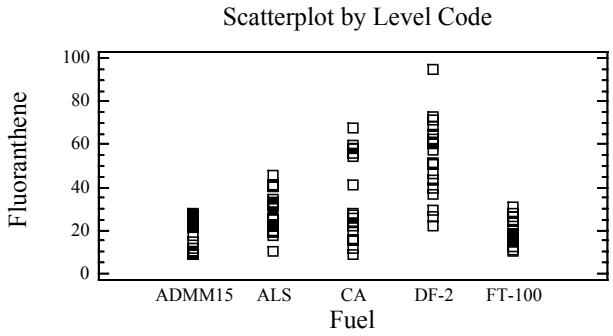
Multifactor ANOVA - Fluoranthene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

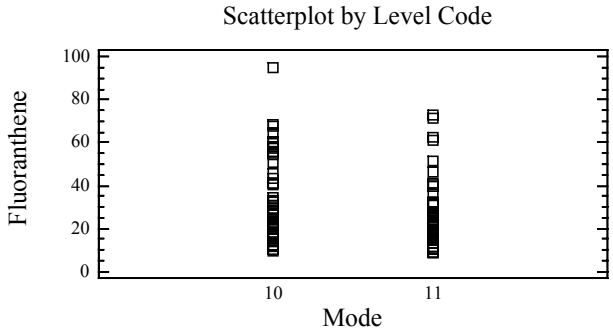
Analysis Summary

Dependent variable: fluoran
Factors:
COND
FUEL
MODE

Number of complete cases: 91







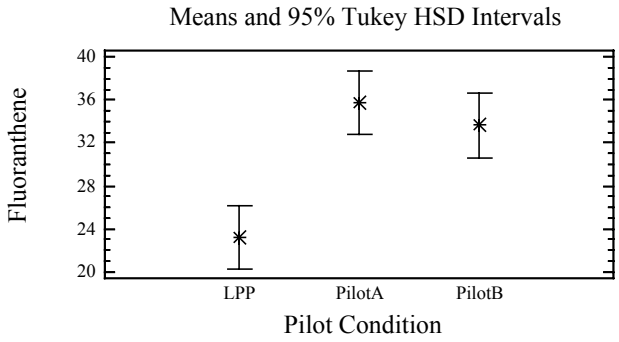
Analysis of Variance for fluoran - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	2718.83	2	1359.41	14.62	0.0000
B:FUEL	14521.4	4	3630.35	39.05	0.0000
C:MODE	1346.19	1	1346.19	14.48	0.0003

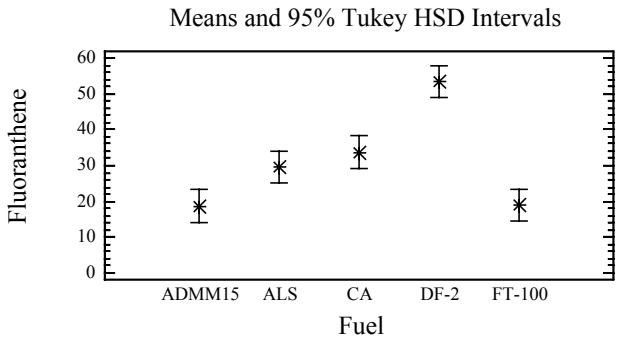
INTERACTIONS					
AB	3221.95	8	402.744	4.33	0.0004
AC	296.078	2	148.039	1.59	0.2118
BC	1271.06	4	317.765	3.42	0.0138
ABC	1164.98	8	145.623	1.57	0.1539
RESIDUAL	5671.34	61	92.9727		
TOTAL (CORRECTED)	30240.5	90			

All F-ratios are based on the residual mean square error.

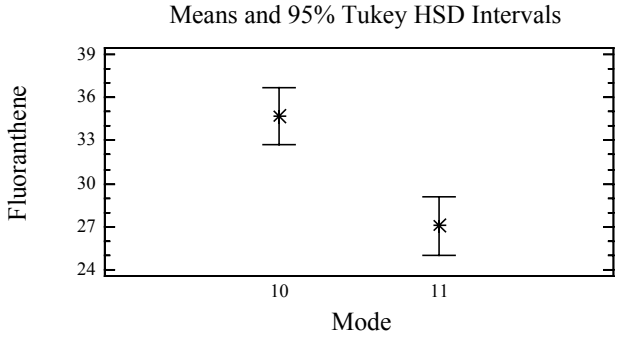
CONCLUSION: Statistically significant differences in the average fluoranthene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, and fuel*mode interaction.



CONCLUSION: The average fluoranthene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: There are three distinct fuel groupings with respect to the average fluoranthene. The average fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The ADMM15 and FT-100 fuels are not significantly different from one another, but are significantly different than the remaining three fuels. Also, the CA and ALS fuels are not significantly different from one another, but are significantly different from the remaining fuels.



CONCLUSION: The average fluoranthene for modes 10 and 11 are significantly different from one another.

Multiple Range Tests for fluoran by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	23.2653	X
PilotB	30	33.6216	X
PilotA	30	35.7437	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-12.4783	5.93261
LPP - PilotB	*-10.3563	5.93261
PilotA - PilotB	2.12207	5.98104

* denotes a statistically significant difference.

Multiple Range Tests for fluoran by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	18.7128	X
FT-100	18	18.8435	X
ALS	19	29.7554	X
CA	18	33.7345	X
DF-2	18	53.338	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-11.0426	8.91537
ADMM15 - CA	*-15.0217	9.03505
ADMM15 - DF-2	*-34.6252	9.03505
ADMM15 - FT-100	-0.130752	9.03505
ALS - CA	-3.97909	8.91537
ALS - DF-2	*-23.5826	8.91537
ALS - FT-100	*10.9119	8.91537
CA - DF-2	*-19.6035	9.03505
CA - FT-100	*14.891	9.03505
DF-2 - FT-100	*34.4944	9.03505

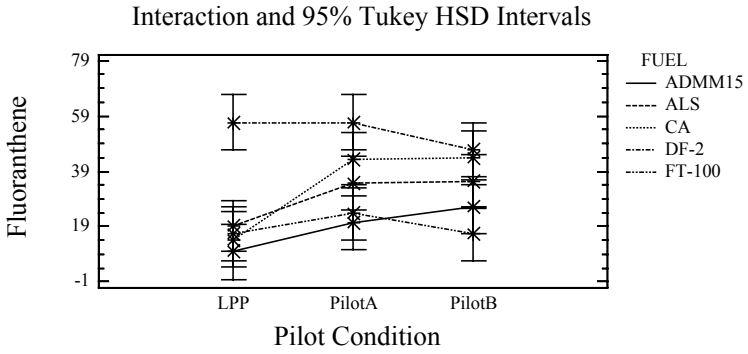
* denotes a statistically significant difference.

Multiple Range Tests for fluoran by MODE

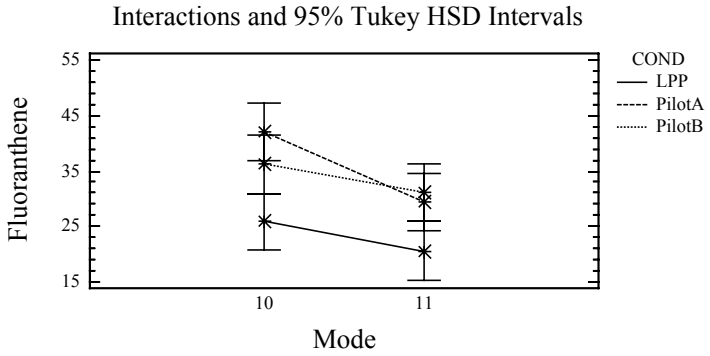
Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
11	45	27.0255	X
10	46	34.7282	X

Contrast	Difference	+/- Limits
10 - 11	*7.70273	4.04262

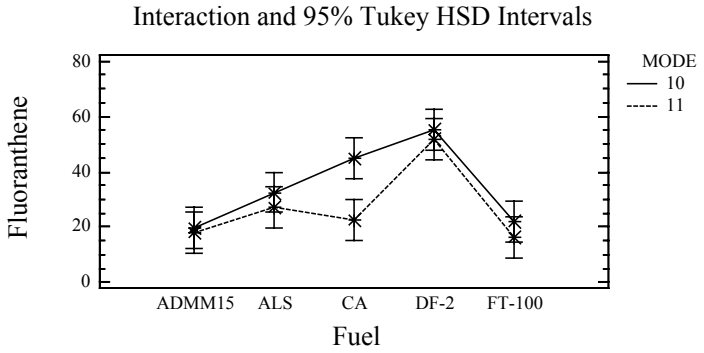
* denotes a statistically significant difference.



CONCLUSION: The trend in the average fluoranthene across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels. The average fluoranthene for the DF-2 fuel at the LPP condition is significantly different than the other four fuels.



CONCLUSION: There is no significant interaction in the average fluoranthene among the pilot condition and mode combinations.



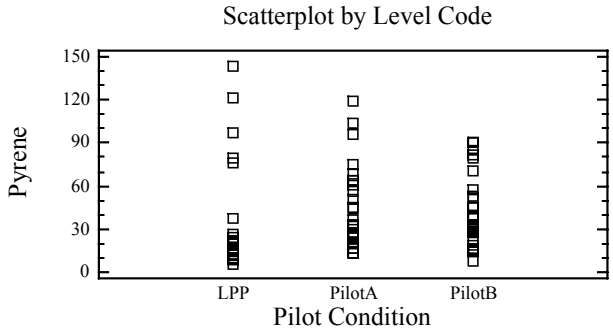
CONCLUSION: The trends in the average fluoranthene for modes 10 and 11 are significantly different at the CA fuel. Otherwise, the average fluoranthene for the two modes are not significantly different across the remaining four fuels.

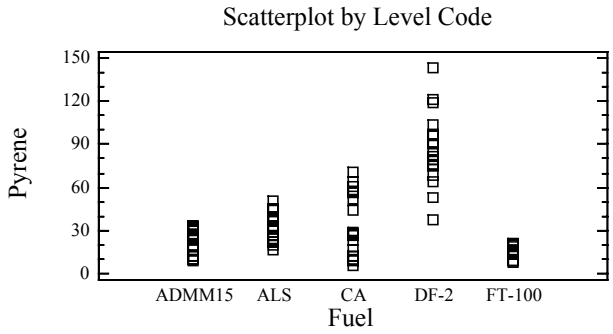
Multifactor ANOVA - Pyrene (mirco g/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

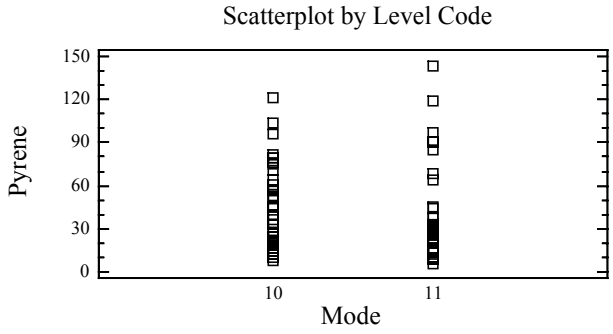
Analysis Summary

Dependent variable: pyrene
Factors:
COND
FUEL
MODE

Number of complete cases: 91







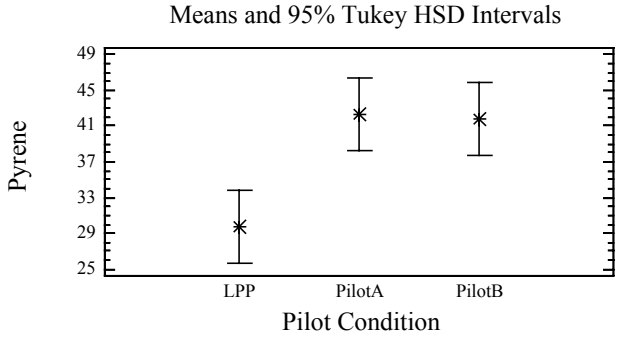
Analysis of Variance for pyrene - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	3128.95	2	1564.47	8.88	0.0004
B:FUEL	57792.3	4	14448.1	82.01	0.0000
C:MODE	933.572	1	933.572	5.30	0.0248

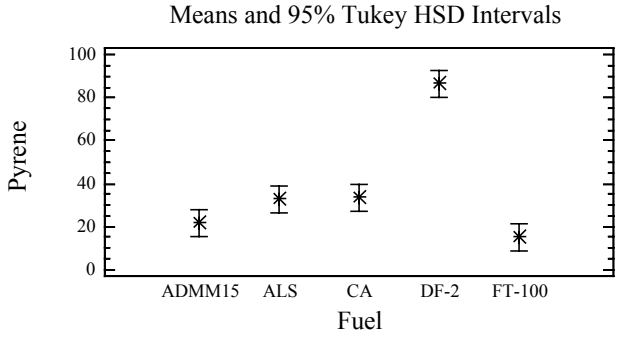
INTERACTIONS					
AB	4706.65	8	588.331	3.34	0.0031
AC	375.603	2	187.802	1.07	0.3507
BC	1618.66	4	404.665	2.30	0.0692
ABC	951.124	8	118.89	0.67	0.7116
RESIDUAL	10746.4	61	176.171		
TOTAL (CORRECTED)	80392.5	90			

All F-ratios are based on the residual mean square error.

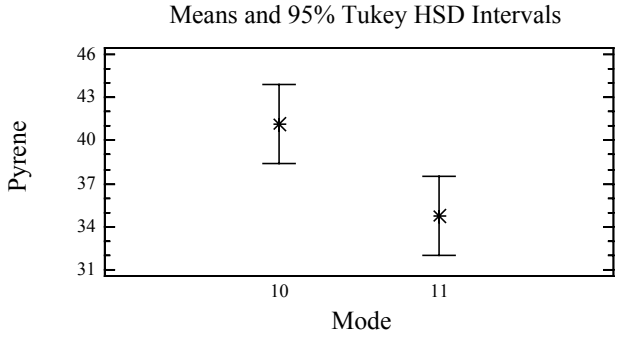
CONCLUSION: Statistically significant differences in the average pyrene among the pilot conditions, fuels, modes, and pilot condition*fuel interaction.



CONCLUSION: The average pyrene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: There are several distinct fuel groupings with respect to the average pyrene. The average pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The FT-100 fuel is significantly different than the ALS and CA fuels, but not significantly different than the ADMM15 fuel.



CONCLUSION: The average pyrene for modes 10 and 11 are significantly different from one another.

Multiple Range Tests for pyrene by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	29.6699	X
PilotB	30	41.7887	X
PilotA	30	42.3395	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-12.6696	8.16647
LPP - PilotB	*-12.1188	8.16647
PilotA - PilotB	0.550867	8.23314

* denotes a statistically significant difference.

Multiple Range Tests for pyrene by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	15.0864	X
ADMM15	18	21.6978	XX
ALS	19	32.749	X
CA	18	33.4433	X
DF-2	18	86.6869	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-11.0512	12.2724
ADMM15 - CA	-11.7455	12.4371
ADMM15 - DF-2	*-64.9892	12.4371
ADMM15 - FT-100	6.61132	12.4371
ALS - CA	-0.694279	12.2724
ALS - DF-2	*-53.9379	12.2724
ALS - FT-100	*17.6626	12.2724
CA - DF-2	*-53.2437	12.4371
CA - FT-100	*18.3568	12.4371
DF-2 - FT-100	*71.6005	12.4371

* denotes a statistically significant difference.

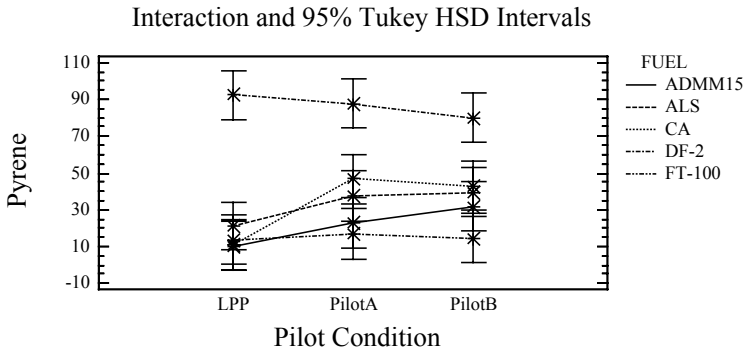
Multiple Range Tests for pyrene by MODE

Method: 95.0 percent Tukey HSD

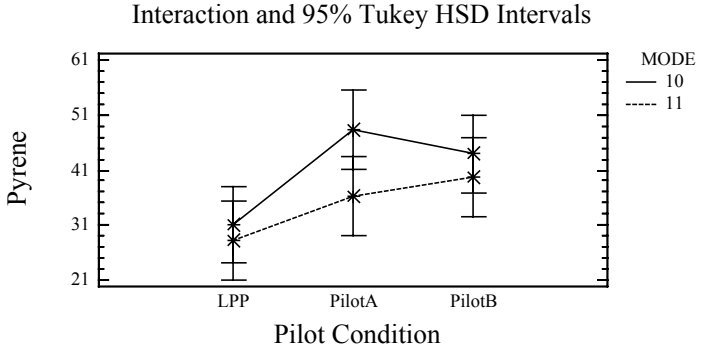
MODE	Count	LS Mean	Homogeneous Groups
11	45	34.7254	X
10	46	41.14	X

Contrast	Difference	+/- Limits
10 - 11	*6.41454	5.56482

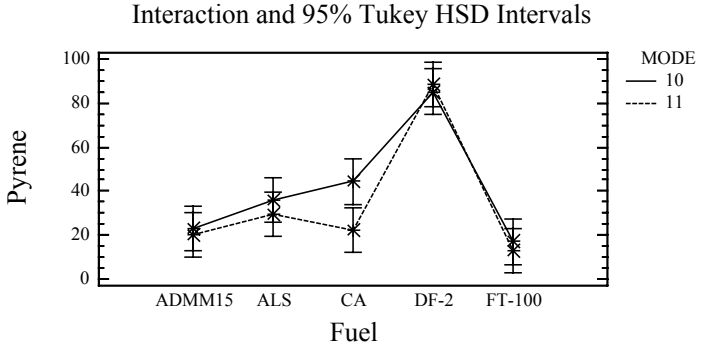
* denotes a statistically significant difference.



CONCLUSION: The trend in the average pyrene across the pilot conditions for the DF-2 fuel is significantly different than the trends for the remaining four fuels.



CONCLUSION: There is no significant interaction in the average pyrene among the pilot condition and mode combinations.



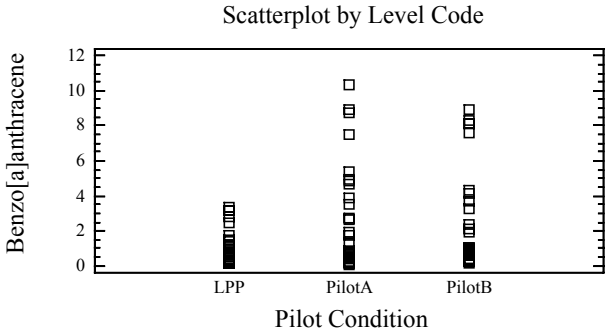
CONCLUSION: There is no significant interaction in the average pyrene among the fuel and mode combinations.

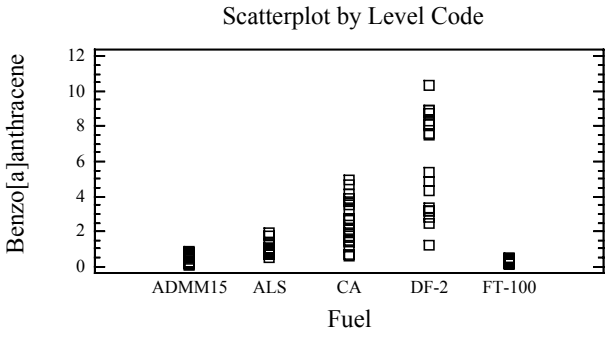
Multifactor ANOVA - Benzo[a]anthracene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

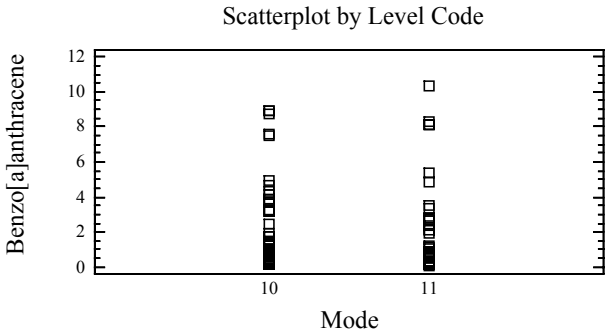
Analysis Summary

Dependent variable: benzoaan
Factors:
COND
FUEL
MODE

Number of complete cases: 90







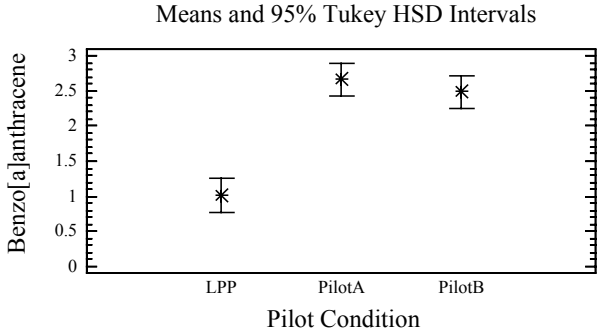
Analysis of Variance for benzoaan - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	48.5995	2	24.2997	40.74	0.0000
B:FUEL	402.558	4	100.639	168.71	0.0000
C:MODE	3.88467	1	3.88467	6.51	0.0133

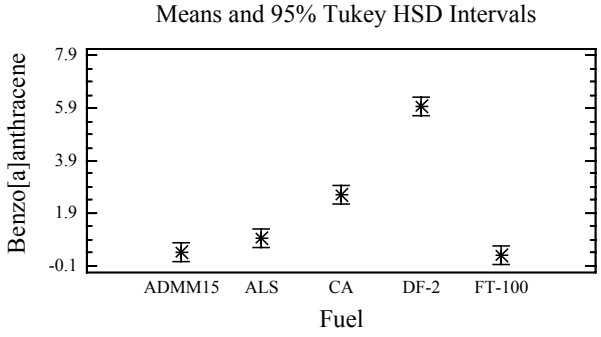
INTERACTIONS					
AB	67.7529	8	8.46911	14.20	0.0000
AC	2.79427	2	1.39713	2.34	0.1049
BC	4.41053	4	1.10263	1.85	0.1314
ABC	4.58466	8	0.573083	0.96	0.4750
RESIDUAL	35.7914	60	0.596523		
TOTAL (CORRECTED)	573.429	89			

All F-ratios are based on the residual mean square error.

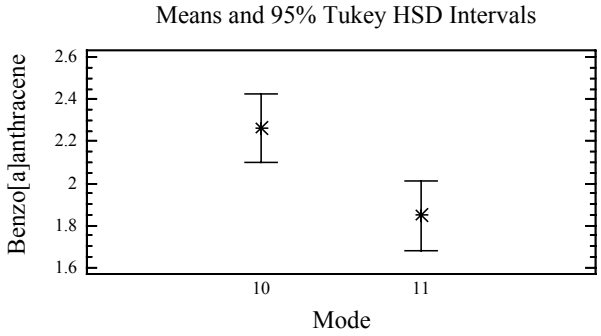
CONCLUSION: Statistically significant differences in the average benzo[a]anthracene among the pilot conditions, fuels, modes, and pilot condition*mode interaction.



CONCLUSION: The average benzo[a]anthracene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: There are three distinct fuel groupings with respect to the average benzo[a]anthracene. Fuels DF-2 and CA are significantly different from one another and the remaining three fuels. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly different than the other other two fuels.



CONCLUSION: The average benzo[a]anthracene for mode 10 is significantly different than mode 11.

Multiple Range Tests for benzoaan by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	30	1.0117	X
PilotB	30	2.48863	X
PilotA	30	2.66345	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-1.65175	0.479284
LPP - PilotB	*-1.47694	0.479284
PilotA - PilotB	0.174814	0.479284

* denotes a statistically significant difference.

Multiple Range Tests for benzoaan by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	17	0.301925	X
ADMM15	18	0.424917	X
ALS	19	0.966186	X
CA	18	2.61	X
DF-2	18	5.96993	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.541269	0.714488
ADMM15 - CA	*-2.18508	0.724079
ADMM15 - DF-2	*-5.54501	0.724079
ADMM15 - FT-100	0.122992	0.73465
ALS - CA	*-1.64381	0.714488
ALS - DF-2	*-5.00374	0.714488
ALS - FT-100	0.664261	0.725199
CA - DF-2	*-3.35993	0.724079
CA - FT-100	*2.30807	0.73465
DF-2 - FT-100	*5.668	0.73465

* denotes a statistically significant difference.

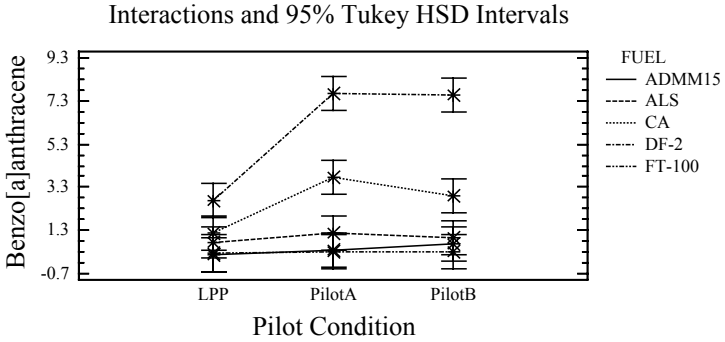
Multiple Range Tests for benzoaan by MODE

Method: 95.0 percent Tukey HSD

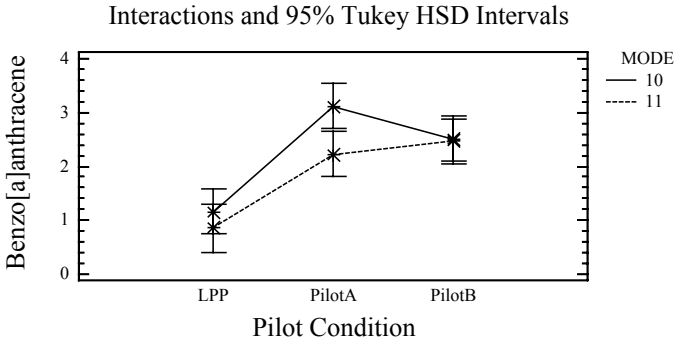
MODE	Count	LS Mean	Homogeneous Groups
11	44	1.84597	X
10	46	2.26321	X

Contrast	Difference	+/- Limits
10 - 11	*0.417242	0.32578

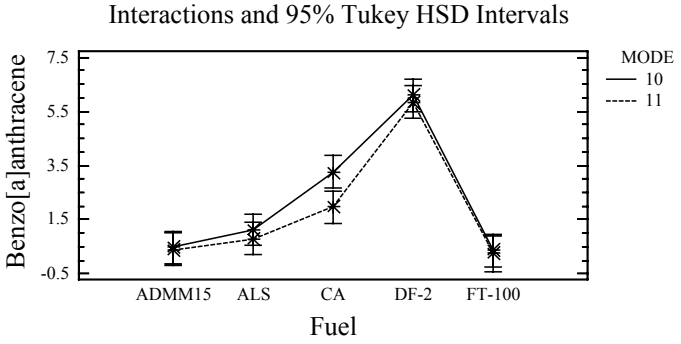
* denotes a statistically significant difference.



CONCLUSION: The trends in the average benzo[a]anthracene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average benzo[a]anthracene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, ALS, and FT-100 fuels.



CONCLUSION: There is no significant interaction in the average benzo[a]anthracene among the pilot condition and mode combinations.



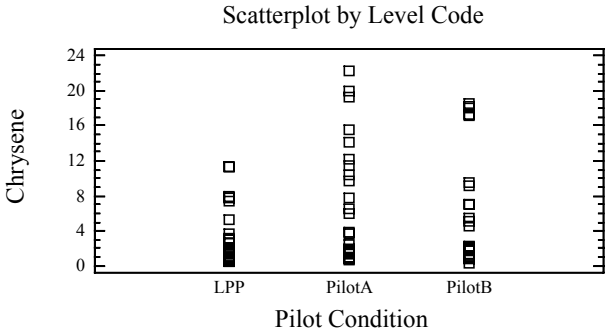
CONCLUSION: There is no significant interaction in the average benzo[a]anthracene among the fuel and mode combinations.

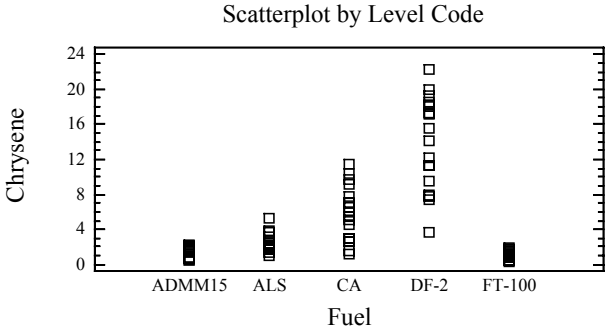
Multifactor ANOVA - Chrysene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

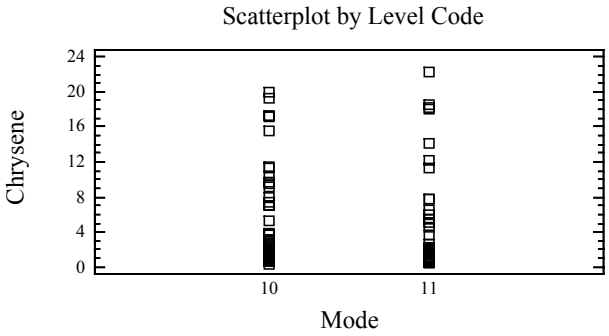
Analysis Summary

Dependent variable: chrysene
Factors:
COND
FUEL
MODE

Number of complete cases: 91







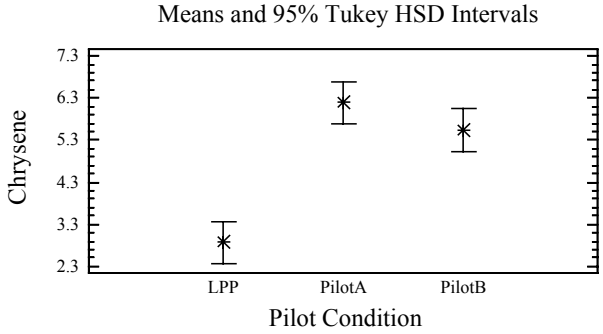
Analysis of Variance for chrysene - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	188.566	2	94.2828	35.03	0.0000
B:FUEL	2128.88	4	532.22	197.75	0.0000
C:MODE	14.6927	1	14.6927	5.46	0.0228

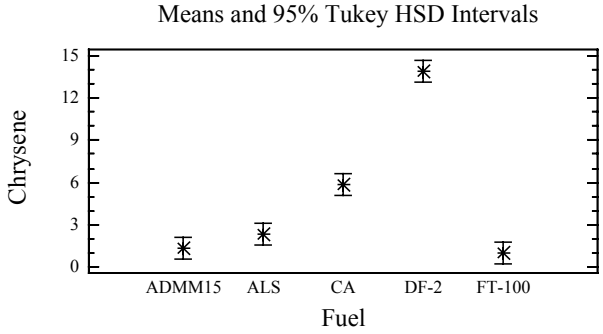
INTERACTIONS					
AB	247.004	8	30.8756	11.47	0.0000
AC	14.0682	2	7.03408	2.61	0.0815
BC	18.4527	4	4.61319	1.71	0.1585
ABC	23.1032	8	2.8879	1.07	0.3938
RESIDUAL	164.177	61	2.69143		
TOTAL (CORRECTED)	2790.75	90			

All F-ratios are based on the residual mean square error.

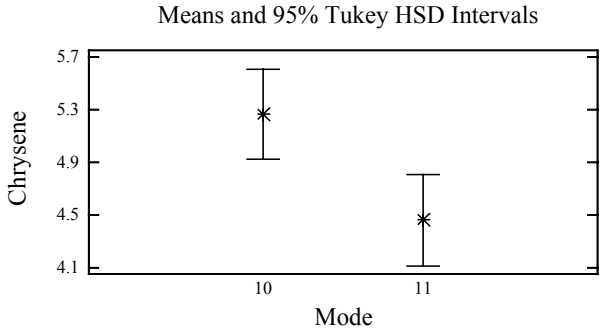
CONCLUSION: Statistically significant differences in the average chrysene among the pilot conditions, fuels, modes, and pilot condition*fuel interaction.



CONCLUSION: The average chrysene for the Pilot A and Pilot B conditions are not significantly different from one another, but are significantly different from the LPP condition.



CONCLUSION: There are three distinct fuel groupings with respect to the average chrysene. Fuels DF-2 and CA are significantly different from one another and the remaining three fuels. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly differnt than the other two fuels.



CONCLUSION: The average chrysene for mode 10 is significantly different than mode 11.

Multiple Range Tests for chrysene by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	2.86821	X
PilotB	30	5.53075	X
PilotA	30	6.18938	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-3.32117	1.00939
LPP - PilotB	*-2.66254	1.00939
PilotA - PilotB	0.658631	1.01763

* denotes a statistically significant difference.

Multiple Range Tests for chrysene by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	1.00794	X
ADMM15	18	1.27994	X
ALS	19	2.27269	X
CA	18	5.7963	X
DF-2	18	13.957	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.992748	1.51689
ADMM15 - CA	*-4.51636	1.53725
ADMM15 - DF-2	*-12.6771	1.53725
ADMM15 - FT-100	0.272006	1.53725
ALS - CA	*-3.52361	1.51689
ALS - DF-2	*-11.6843	1.51689
ALS - FT-100	1.26475	1.51689
CA - DF-2	*-8.16073	1.53725
CA - FT-100	*4.78836	1.53725
DF-2 - FT-100	*12.9491	1.53725

* denotes a statistically significant difference.

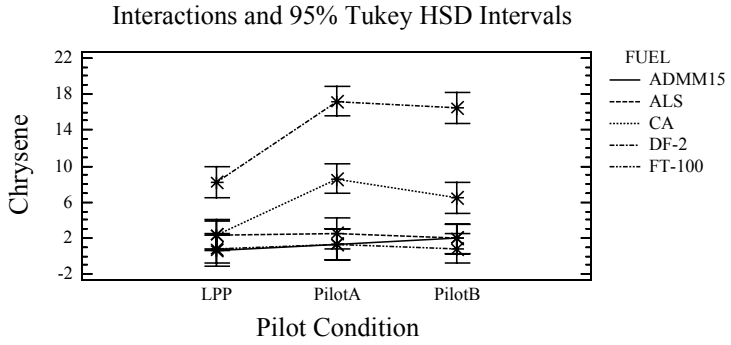
Multiple Range Tests for chrysene by MODE

Method: 95.0 percent Tukey HSD

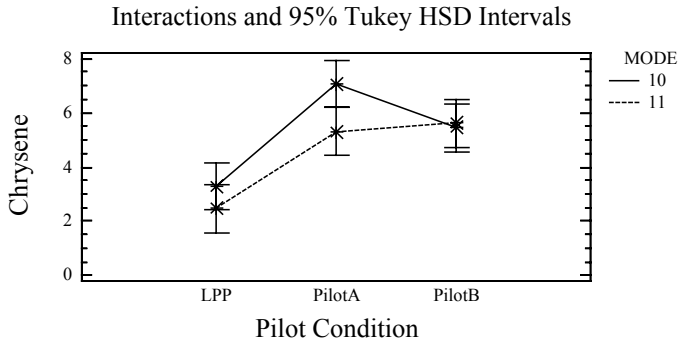
MODE	Count	LS Mean	Homogeneous Groups
11	45	4.46042	X
10	46	5.26514	X

Contrast	Difference	+/- Limits
10 - 11	*0.804715	0.687822

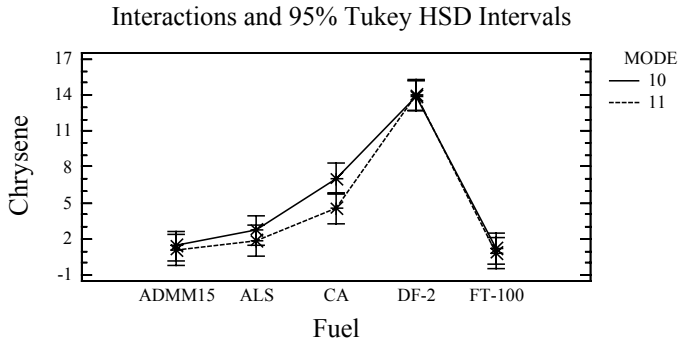
* denotes a statistically significant difference.



CONCLUSION: The trends in the average chrysene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average chrysene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.



CONCLUSION: There is no significant interaction in the average chrysene among the pilot condition and mode combinations.



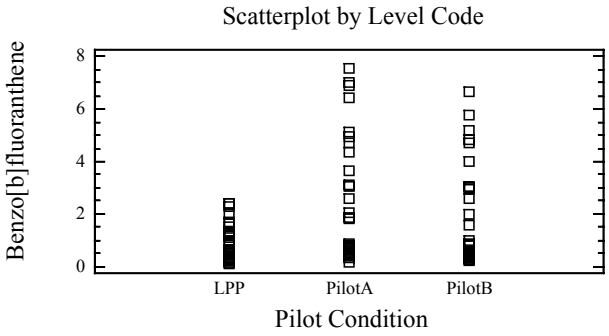
CONCLUSION: There is no significant interaction in the average chrysene among the fuel and mode combinations.

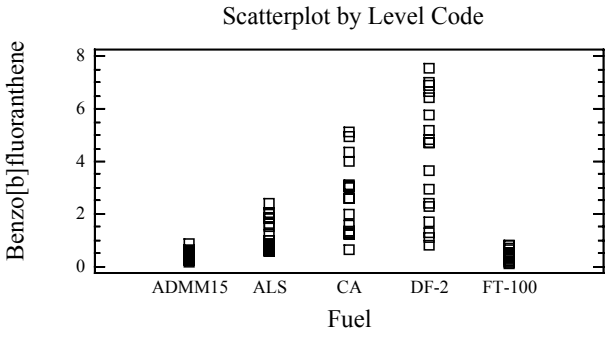
Multifactor ANOVA - Benzo[b]fluoranthene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

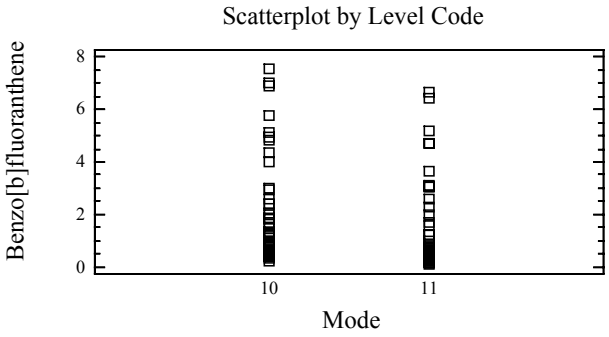
Analysis Summary

Dependent variable: benzobfl
Factors:
COND
FUEL
MODE

Number of complete cases: 90







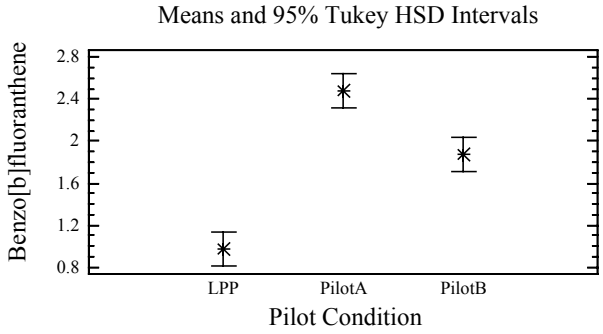
Analysis of Variance for benzobfl - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	33.7923	2	16.8961	61.70	0.0000
B:FUEL	187.458	4	46.8646	171.14	0.0000
C:MODE	6.52731	1	6.52731	23.84	0.0000

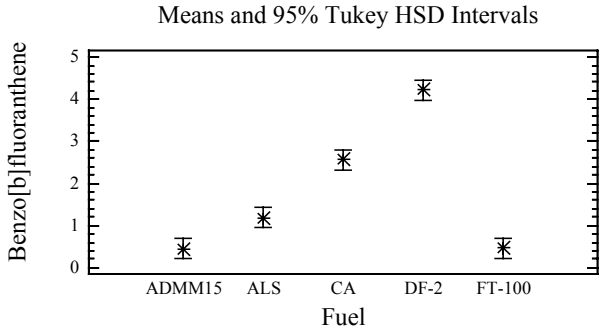
INTERACTIONS					
AB	56.3	8	7.0375	25.70	0.0000
AC	5.08814	2	2.54407	9.29	0.0003
BC	2.47311	4	0.618277	2.26	0.0734
ABC	5.72437	8	0.715547	2.61	0.0160
RESIDUAL	16.4299	60	0.273831		
TOTAL (CORRECTED)	314.118	89			

All F-ratios are based on the residual mean square error.

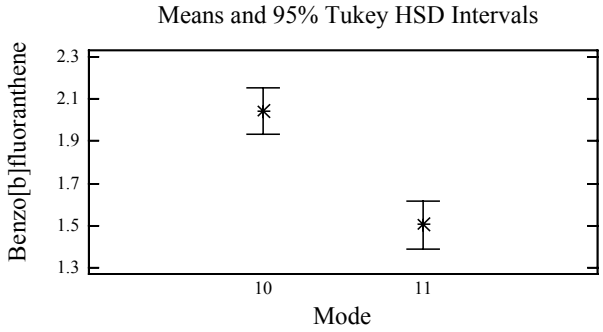
CONCLUSION: Statistically significant differences in the average benzo[b]fluoranthene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, pilot condition*mode interaction, and the three-factor interaction.



CONCLUSION: The average benzo[b]fluoranthene for the three pilot conditions are all significantly different from one another.



CONCLUSION: The average benzo[b]fluoranthene for the ALS, CA, and DF-2 fuels are significantly different from one another and the remaining two fuels. The average benzo[b]fluoranthene for the ADMM15 and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average benzo[b]fluoranthene for modes 10 and 11 are significantly different from one another.

Multiple Range Tests for benzobfl by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	30	0.974513	X
PilotB	30	1.86744	X
PilotA	30	2.47698	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-1.50247	0.324729
LPP - PilotB	*-0.892926	0.324729
PilotA - PilotB	*0.60954	0.324729

* denotes a statistically significant difference.

Multiple Range Tests for benzobfl by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	18	0.440325	X
FT-100	18	0.458957	X
ALS	19	1.18837	X
CA	17	2.55696	X
DF-2	18	4.22027	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.748046	0.484086
ADMM15 - CA	*-2.11664	0.497747
ADMM15 - DF-2	*-3.77994	0.490584
ADMM15 - FT-100	-0.018632	0.490584
ALS - CA	*-1.36859	0.491343
ALS - DF-2	*-3.0319	0.484086
ALS - FT-100	*0.729414	0.484086
CA - DF-2	*-1.6633	0.497747
CA - FT-100	*2.09801	0.497747
DF-2 - FT-100	*3.76131	0.490584

* denotes a statistically significant difference.

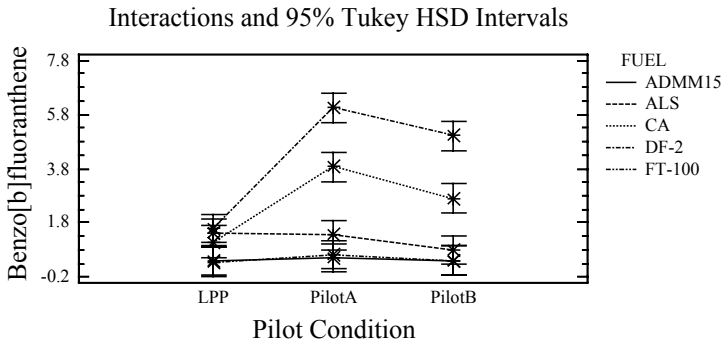
Multiple Range Tests for benzobfl by MODE

Method: 95.0 percent Tukey HSD

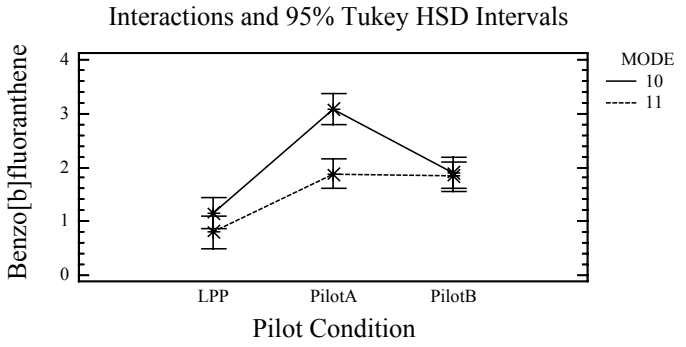
MODE	Count	LS Mean	Homogeneous Groups
11	44	1.50255	X
10	46	2.0434	X

Contrast	Difference	+/- Limits
10 - 11	*0.540852	0.220726

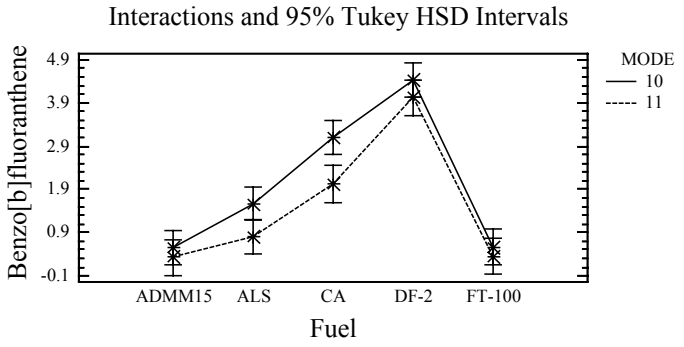
* denotes a statistically significant difference.



CONCLUSION: The trends in the average benzo[b]fluoranthene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average benzo[b]fluoranthene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.



CONCLUSION: The average benzo[b]fluoranthene at the Pilot A condition for Mode 10 is significantly different than Mode 11. There is no significant difference in the average benzo[b]fluoranthene between the two modes at the LPP or Pilot B conditions.



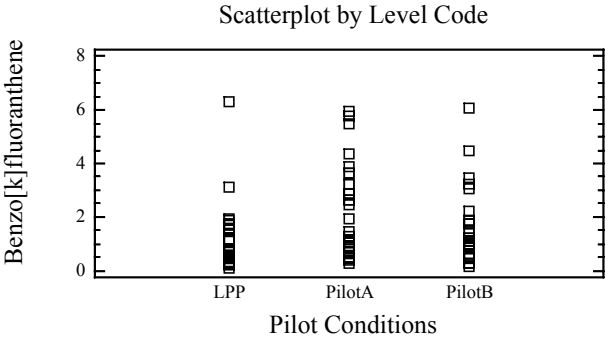
CONCLUSION: There is no significant interaction in the average benzo[b]fluoranthene among the fuel and mode combinations.

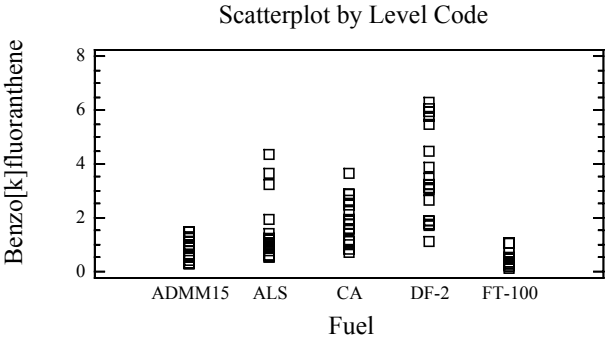
Multifactor ANOVA - Benzo[k]fluoranthene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

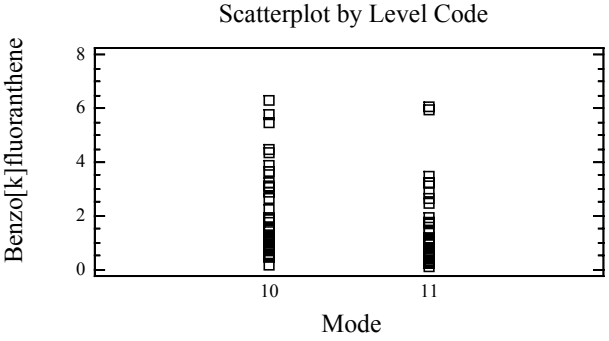
Analysis Summary

Dependent variable: benzokfl
Factors:
COND
FUEL
MODE

Number of complete cases: 90







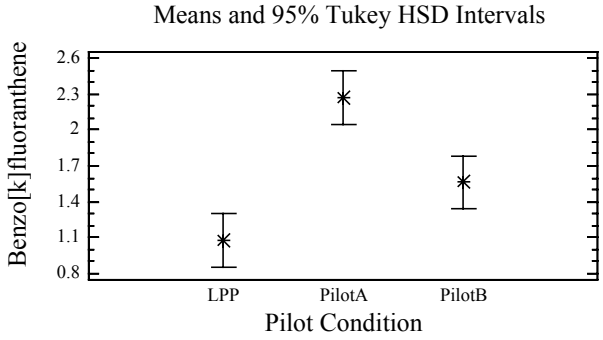
Analysis of Variance for benzokfl - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	21.4951	2	10.7475	20.33	0.0000
B:FUEL	105.475	4	26.3688	49.89	0.0000
C:MODE	7.90494	1	7.90494	14.96	0.0003

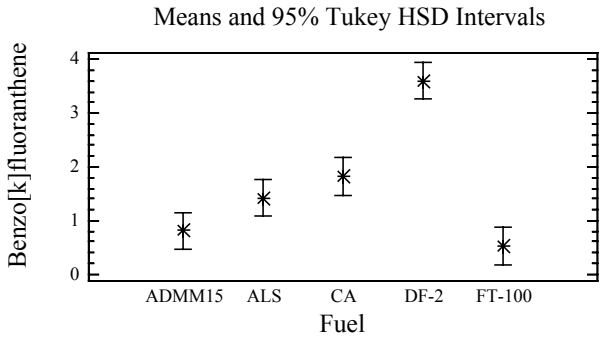
INTERACTIONS					
AB	8.67666	8	1.08458	2.05	0.0551
AC	5.3645	2	2.68225	5.07	0.0092
BC	2.33049	4	0.582623	1.10	0.3638
ABC	9.53079	8	1.19135	2.25	0.0354
RESIDUAL	31.7128	60	0.528547		
TOTAL (CORRECTED)	192.186	89			

All F-ratios are based on the residual mean square error.

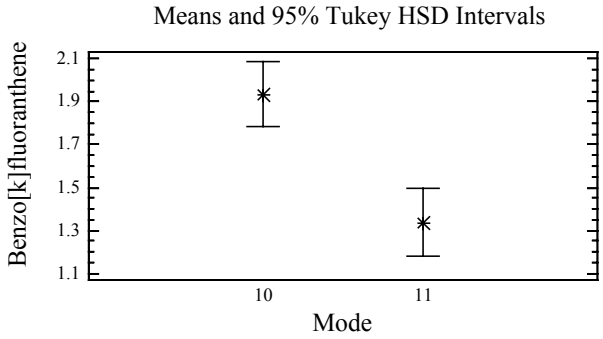
CONCLUSION: Statistically significant differences in the average benzo[b]fluoranthene among the pilot conditions, fuels, modes, pilot condition*mode interaction, and the three-factor interaction.



CONCLUSION: The average benzo[f]fluoranthene for the three pilot conditions are significantly different from one another.



CONCLUSION: There are several distinct fuel groupings with respect to the average benzo[k]fluoranthene. The DF-2 fuel is significantly different from the remaining four fuels. The CA fuel is significantly different than the ADMM15 and the FT-100 fuels, but not significantly different than the ALS fuel. Also, the ALS fuel is significantly different than the FT-100 fuel.



CONCLUSION: The average benzo[k]fluoranthene for mode 10 is significantly different than mode 11.

Multiple Range Tests for benzokfl by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	30	1.07438	X
PilotB	30	1.56063	X
PilotA	30	2.27093	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-1.19656	0.45115
LPP - PilotB	*-0.486254	0.45115
PilotA - PilotB	*0.710302	0.45115

* denotes a statistically significant difference.

Multiple Range Tests for benzokfl by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	0.525045	X
ADMM15	18	0.817921	XX
ALS	19	1.4175	XX
CA	17	1.81074	X
DF-2	18	3.60536	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.599576	0.672548
ADMM15 - CA	*-0.992818	0.691526
ADMM15 - DF-2	*-2.78744	0.681575
ADMM15 - FT-100	0.292877	0.681575
ALS - CA	-0.393242	0.68263
ALS - DF-2	*-2.18787	0.672548
ALS - FT-100	*0.892453	0.672548
CA - DF-2	*-1.79462	0.691526
CA - FT-100	*1.28569	0.691526
DF-2 - FT-100	*3.08032	0.681575

* denotes a statistically significant difference.

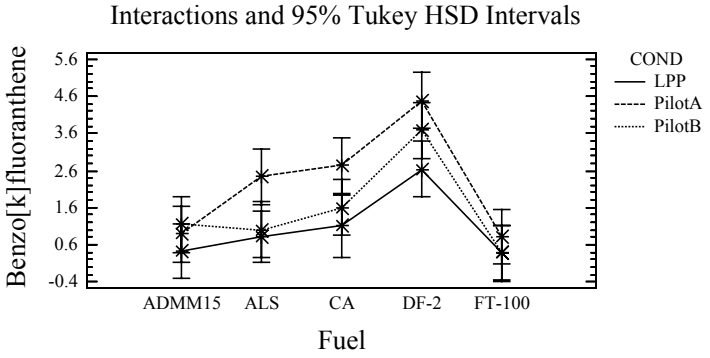
Multiple Range Tests for benzokfl by MODE

Method: 95.0 percent Tukey HSD

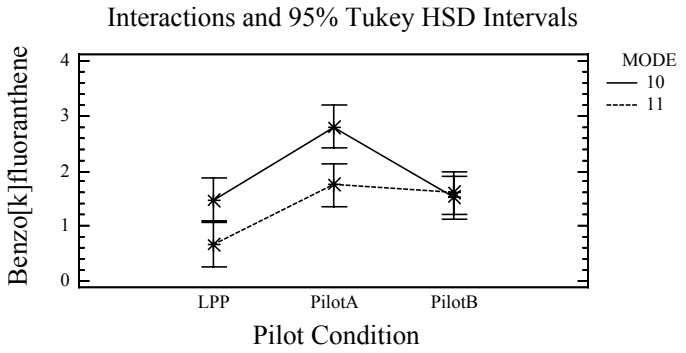
MODE	Count	LS Mean	Homogeneous Groups
11	44	1.33772	X
10	46	1.93291	X

Contrast	Difference	+/- Limits
10 - 11	*0.595196	0.306657

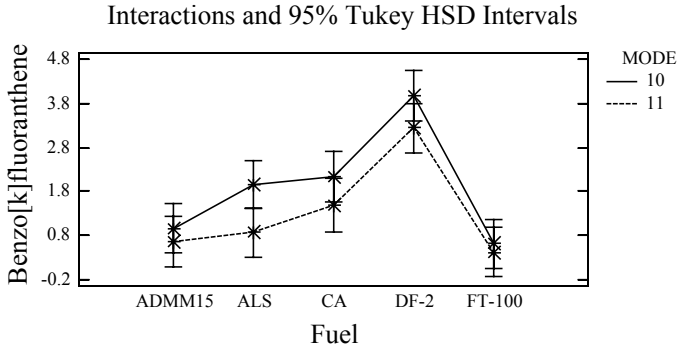
* denotes a statistically significant difference.



CONCLUSION: There is no significant interaction in the average benzo[k]fluoranthene among the fuel and pilot condition combinations.



CONCLUSION: The average benzo[k]fluoranthene at the Pilot A condition for Mode 10 is significantly different than Mode 11. There is no significant difference in the average benzo[k]fluoranthene between the two modes at the LPP or Pilot B conditions.



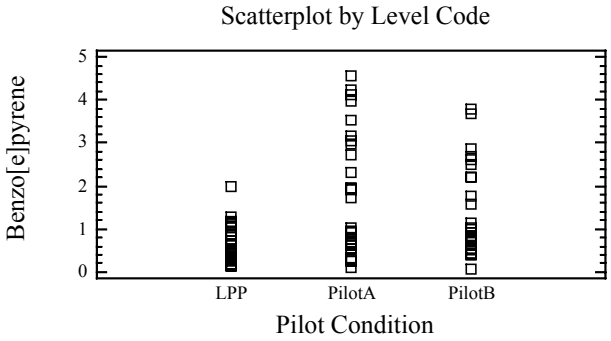
CONCLUSION: There is no significant interaction in the average benzo[k]fluoranthene among the fuel and mode combinations.

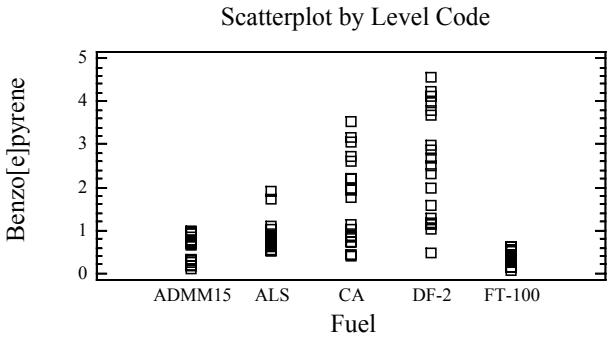
Multifactor ANOVA - Benzo[e]pyrene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

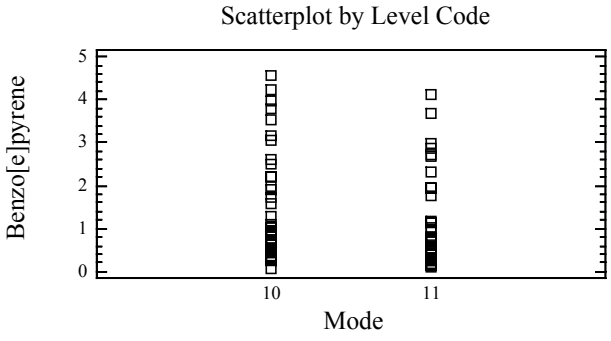
Analysis Summary

Dependent variable: benzoepy
Factors:
COND
FUEL
MODE

Number of complete cases: 91







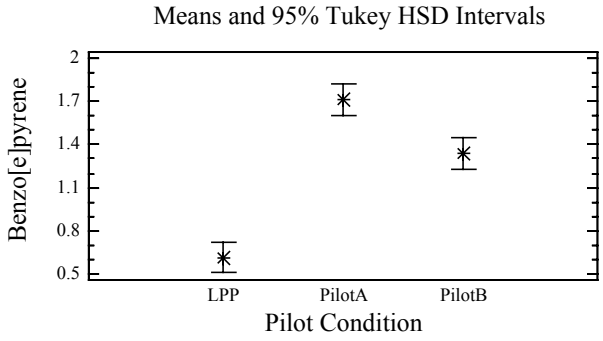
Analysis of Variance for benzoepy - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	19.0613	2	9.53063	74.74	0.0000
B:FUEL	61.2053	4	15.3013	119.99	0.0000
C:MODE	3.35117	1	3.35117	26.28	0.0000

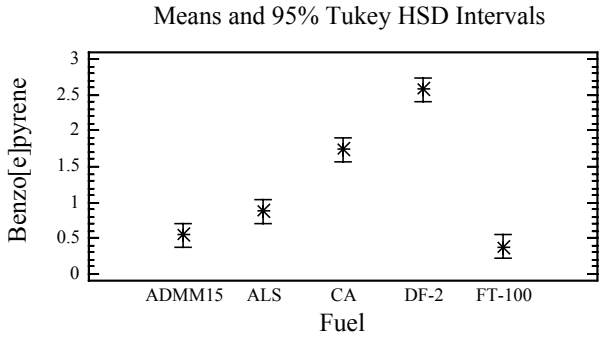
INTERACTIONS					
AB	15.5695	8	1.94619	15.26	0.0000
AC	1.70452	2	0.852262	6.68	0.0024
BC	1.17591	4	0.293977	2.31	0.0683
ABC	1.62589	8	0.203236	1.59	0.1455
RESIDUAL	7.7789	61	0.127523		
TOTAL (CORRECTED)	111.059	90			

All F-ratios are based on the residual mean square error.

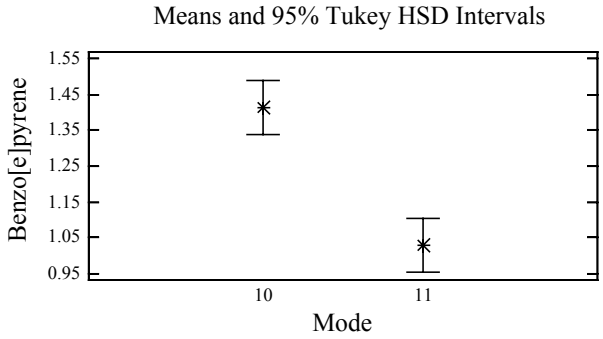
CONCLUSION: Statistically significant differences in the average benzo[e]pyrene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, and pilot condition*mode interaction.



CONCLUSION: The average benzo[e]pyrene for the three pilot conditions are significantly different from one another.



CONCLUSION: There are several distinct fuel groupings with respect to the average benzo[e]pyrene. The DF-2 and CA fuels are significantly different from the remaining three fuels. Also, the ALS fuel is significantly different than the FT-100 fuel.



CONCLUSION: The average benzo[e]pyrene for mode 10 is significantly different than mode 11.

Multiple Range Tests for benzoepy by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	0.613585	X
PilotB	30	1.3361	X
PilotA	30	1.71474	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-1.10116	0.219716
LPP - PilotB	*-0.722515	0.219716
PilotA - PilotB	*0.378641	0.22151

* denotes a statistically significant difference.

Multiple Range Tests for benzoepy by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	0.375599	X
ADMM15	18	0.544484	XX
ALS	19	0.874367	X
CA	18	1.73671	X
DF-2	18	2.57622	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.329883	0.330184
ADMM15 - CA	*-1.19223	0.334616
ADMM15 - DF-2	*-2.03173	0.334616
ADMM15 - FT-100	0.168886	0.334616
ALS - CA	*-0.862343	0.330184
ALS - DF-2	*-1.70185	0.330184
ALS - FT-100	*0.498769	0.330184
CA - DF-2	*-0.839507	0.334616
CA - FT-100	*1.36111	0.334616
DF-2 - FT-100	*2.20062	0.334616

* denotes a statistically significant difference.

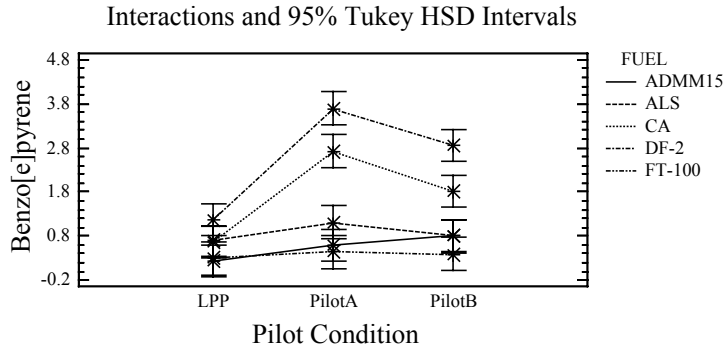
Multiple Range Tests for benzoepy by MODE

Method: 95.0 percent Tukey HSD

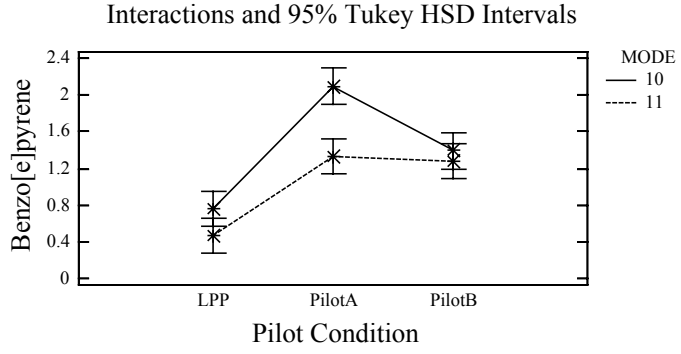
MODE	Count	LS Mean	Homogeneous Groups
11	45	1.02932	X
10	46	1.41363	X

Contrast	Difference	+/- Limits
10 - 11	*0.384317	0.14972

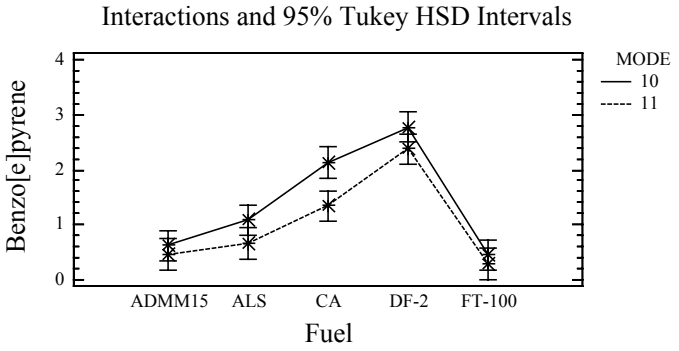
* denotes a statistically significant difference.



CONCLUSION: The trends in the average benzo[e]pyrene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining three fuels. The average benzo[e]pyrene for the DF-2 and CA fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.



CONCLUSION: The average benzo[e]pyrene at the Pilot A condition for Mode 10 is significantly different than Mode 11. There is no significant difference in the average benzo[e]pyrene between the two modes at the LPP or Pilot B conditions.



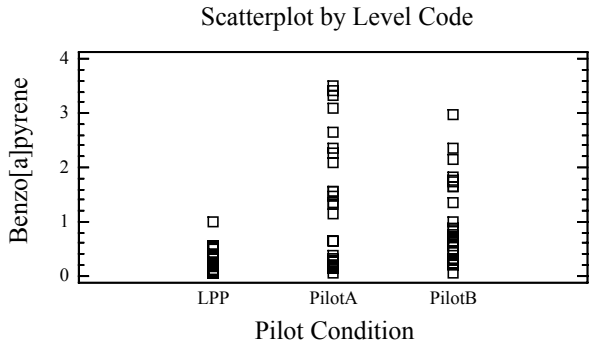
CONCLUSION: There is no significant interaction in the average benzo[e]pyrene among the fuel and mode combinations.

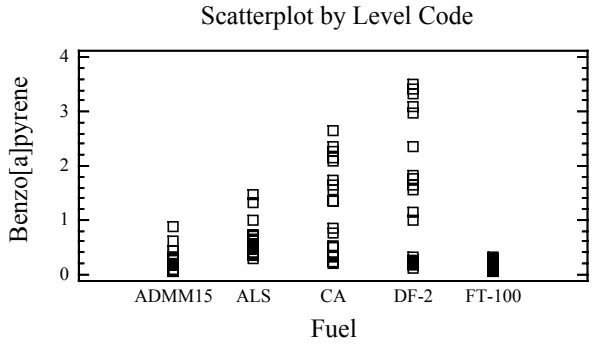
Multifactor ANOVA - Benzo[a]pyrene (µg/kW-hr) Soluble PAH
Three Pilot Conditions Modes 10 and 11

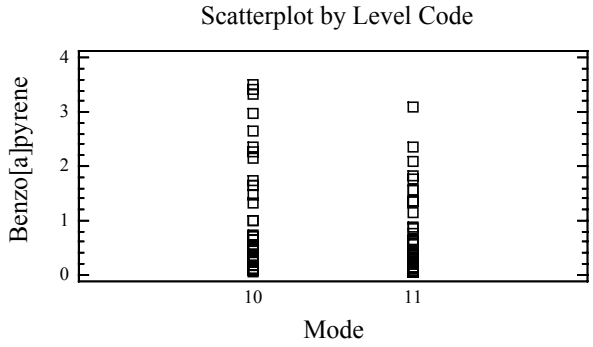
Analysis Summary

Dependent variable: benzoapy
Factors:
COND
FUEL
MODE

Number of complete cases: 90







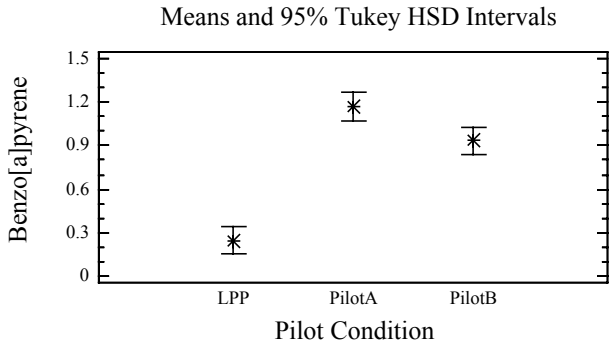
Analysis of Variance for benzoapy - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	13.9325	2	6.96627	70.55	0.0000
B:FUEL	28.6525	4	7.16311	72.54	0.0000

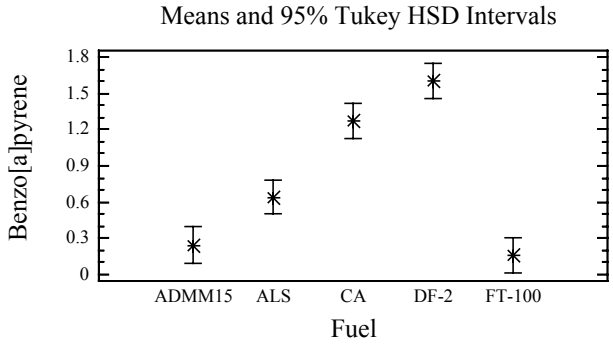
C:MODE	1.90042	1	1.90042	19.25	0.0000
INTERACTIONS					
AB	14.7907	8	1.84884	18.72	0.0000
AC	1.26211	2	0.631057	6.39	0.0030
BC	1.38381	4	0.345953	3.50	0.0123
ABC	1.8229	8	0.227863	2.31	0.0315
RESIDUAL	5.92448	60	0.0987413		
TOTAL (CORRECTED)	69.8823	89			

All F-ratios are based on the residual mean square error.

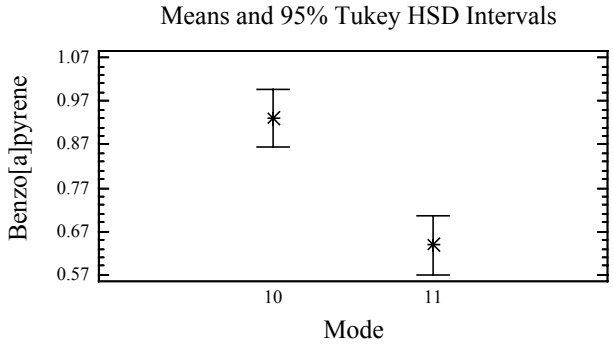
CONCLUSION: Statistically significant differences in the average benzo[a]pyrene among the pilot conditions, fuels, modes, two-factor interactions, and the three-factor interaction fuel*mode*pilot condition.



CONCLUSION: The average benzo[a]pyrene for the three pilot conditions are significantly different from one another.



CONCLUSION: The average benzo[a]pyrene for the DF-2, CA, and ALS fuels are significantly different from one another and the remaining two fuels. The average benzo[a]pyrene for the ADMM15 and FT-100 fuels are not significantly different from one another.



CONCLUSION: The average benzo[a]pyrene for mode 10 is significantly different than mode 11.

Multiple Range Tests for benzoapy by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	31	0.245088	X
PilotB	30	0.932902	X
PilotA	29	1.17383	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-0.92874	0.195106
LPP - PilotB	*-0.687815	0.193419
PilotA - PilotB	*0.240925	0.196671

* denotes a statistically significant difference.

Multiple Range Tests for benzoapy by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	0.160939	X
ADMM15	17	0.242393	X
ALS	19	0.639999	X
CA	18	1.27156	X
DF-2	18	1.6048	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.397606	0.295048
ADMM15 - CA	*-1.02917	0.298893
ADMM15 - DF-2	*-1.36241	0.298893
ADMM15 - FT-100	0.0814542	0.298893
ALS - CA	*-0.631563	0.29069
ALS - DF-2	*-0.964804	0.29069
ALS - FT-100	*0.47906	0.29069
CA - DF-2	*-0.33324	0.294593
CA - FT-100	*1.11062	0.294593
DF-2 - FT-100	*1.44386	0.294593

* denotes a statistically significant difference.

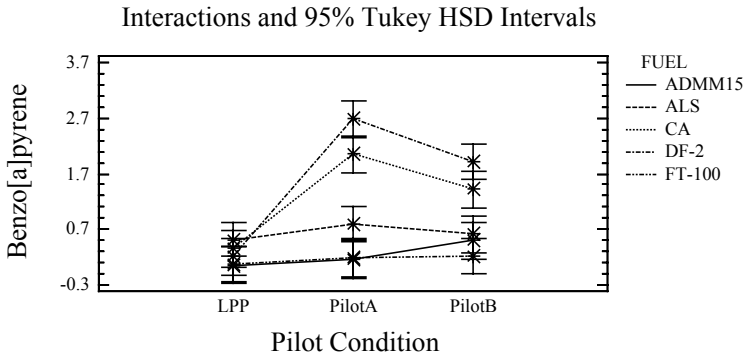
Multiple Range Tests for benzoapy by MODE

Method: 95.0 percent Tukey HSD

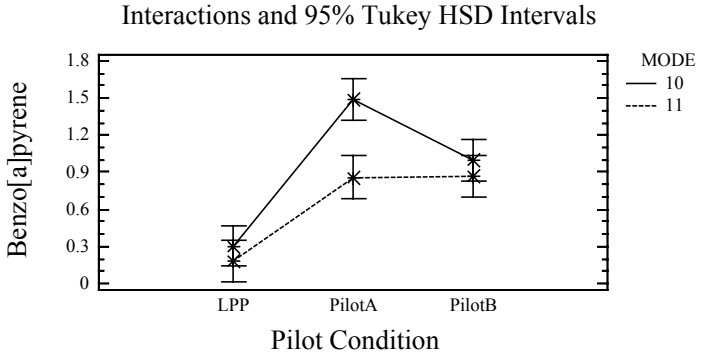
MODE	Count	LS Mean	Homogeneous Groups
11	44	0.638022	X
10	46	0.929856	X

Contrast	Difference	+/- Limits
10 - 11	*0.291834	0.132544

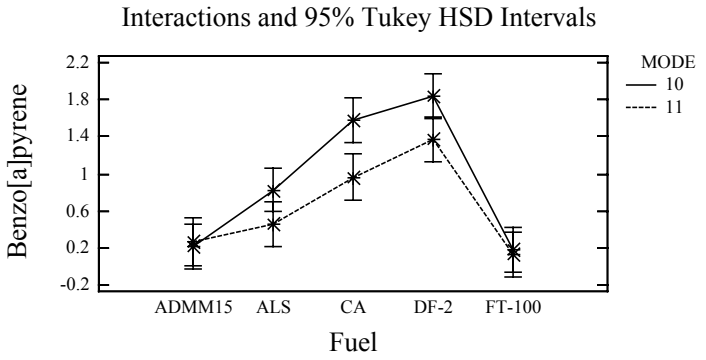
* denotes a statistically significant difference.



CONCLUSION: The trends in the average benzo[a]pyrene across the pilot conditions for the CA and DF-2 fuels are significantly different than the trends for the remaining three fuels. The average benzo[a]pyrene for the CA and DF-2 fuels at the Pilot A and Pilot B conditions are significantly different than the ADMM15, FT-100, and ALS fuels.



CONCLUSION: The average benzo[a]pyrene at the Pilot A condition for mode 10 is significantly different than mode 11. There is no significant difference in the average benzo[a]pyrene between the two modes at the LPP or Pilot B conditions.



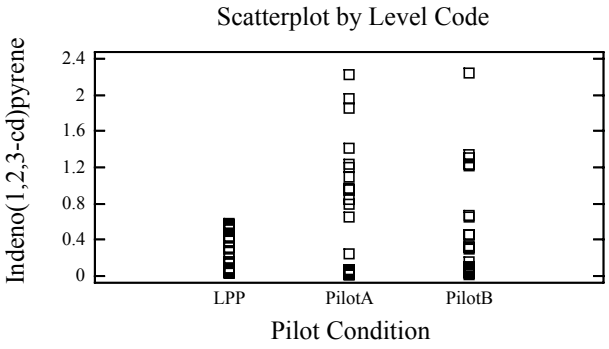
CONCLUSION: The average benzo[a]pyrene for the CA and DF-2 fuels for mode 10 is significantly different than mode 11. There is no significant difference in the average benzo[a]pyrene between the modes for the ADMM15, ALS, or FT-100 fuels.

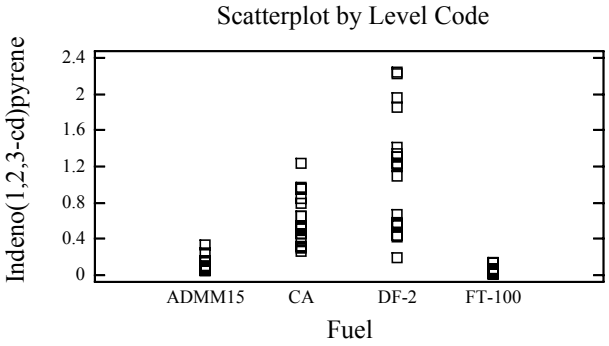
Multifactor ANOVA - Indeno(1,2,3-cd)pyrene (µg/kW-hr) Soluble PAH
Three Pilot Conditions on Four Fuels Modes 10 and 11

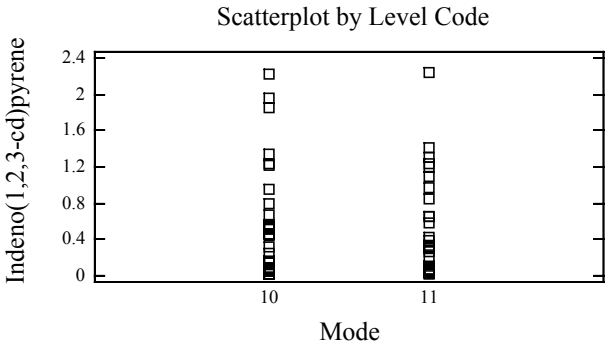
Analysis Summary

Dependent variable: indeno
Factors:
COND
FUEL
MODE

Number of complete cases: 70







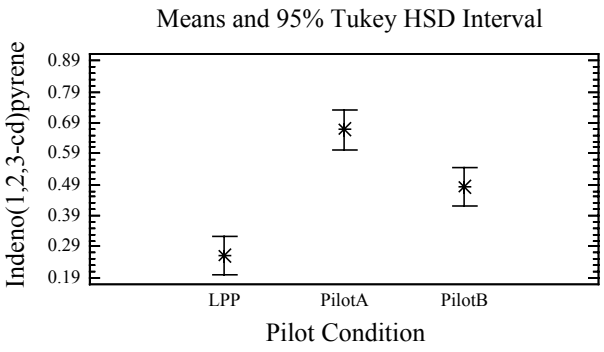
Analysis of Variance for indeno - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	1.88837	2	0.944186	29.96	0.0000
B:FUEL	13.47	3	4.49	142.47	0.0000
C:MODE	0.0979782	1	0.0979782	3.11	0.0845

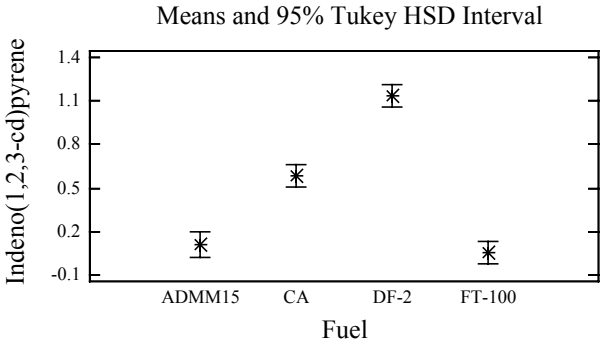
INTERACTIONS					
AB	3.30618	6	0.55103	17.48	0.0000
AC	0.496114	2	0.248057	7.87	0.0011
BC	0.0408507	3	0.0136169	0.43	0.7310
ABC	0.815885	6	0.135981	4.31	0.0016
RESIDUAL	1.44973	46	0.0315159		
TOTAL (CORRECTED)	21.8794	69			

All F-ratios are based on the residual mean square error.

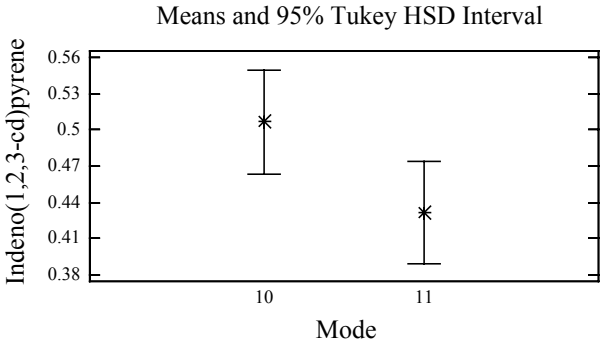
CONCLUSION: Statistically significant differences in the average indeno(1,2,3-cd)pyrene among the pilot conditions, fuels, pilot condition*fuel interaction, pilot condition*mode interaction, and the three-factor interaction pilot condition*fuel*mode.



CONCLUSION: The average indeno(1,2,3-cd)pyrene for the three pilot conditions are significantly different from one another.



CONCLUSION: The average indeno(1,2,3-cd)pyrene for the DF-2 and CA fuels are significantly different from one another and the remaining two fuels. The average indeno(1,2,3-cd)pyrene for the FT-100 and ADMM15 fuels are not significantly different from one another.



CONCLUSION: There is no significant difference in the average indeno(1,2,3-cd)pyrene among the two modes.

Multiple Range Tests for indeno by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	24	0.259249	X
PilotB	24	0.481723	X
PilotA	22	0.666534	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-0.407284	0.126918
LPP - PilotB	*-0.222473	0.124128
PilotA - PilotB	*0.184811	0.126918

* denotes a statistically significant difference.

Multiple Range Tests for indeno by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	0.0485468	X
ADMM15	16	0.10839	X
CA	18	0.581265	X
DF-2	18	1.13847	X

Contrast	Difference	+/- Limits
ADMM15 - CA	*-0.472875	0.162599
ADMM15 - DF-2	*-1.03008	0.162599
ADMM15 - FT-100	0.0598431	0.162599
CA - DF-2	*-0.557207	0.157745
CA - FT-100	*0.532719	0.157745
DF-2 - FT-100	*1.08993	0.157745

* denotes a statistically significant difference.

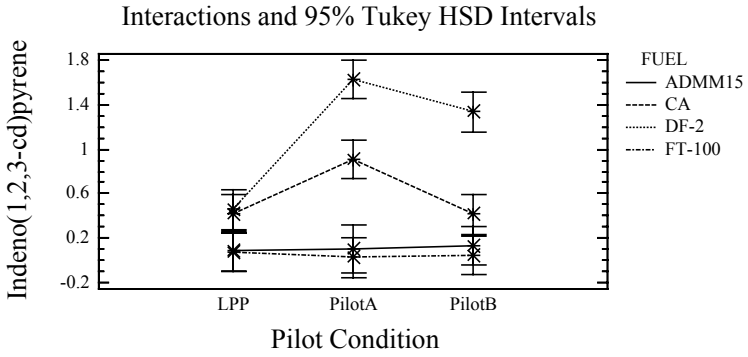
Multifactor ANOVA - indenoMultiple Range Tests for indeno by MODE

Method: 95.0 percent Tukey HSD

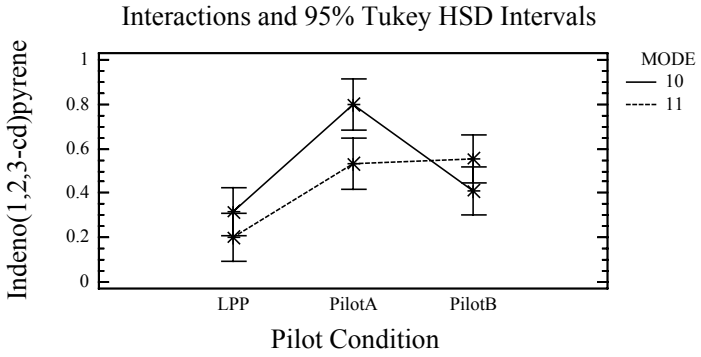
MODE	Count	LS Mean	Homogeneous Groups
11	35	0.431519	X
10	35	0.506818	X

Contrast	Difference	+/- Limits
10 - 11	0.0752996	0.0854216

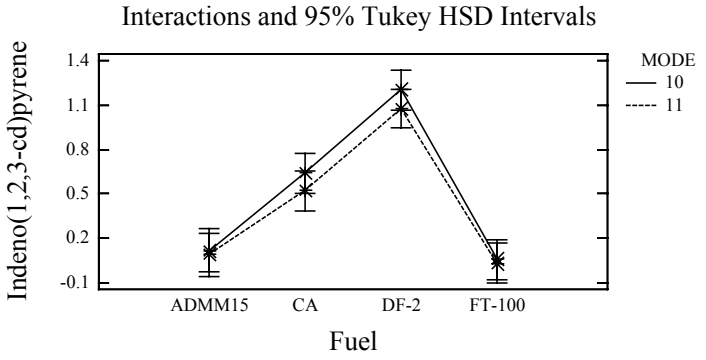
* denotes a statistically significant difference.



CONCLUSION: The trends in the average indeno(1,2,3-cd)pyrene across the pilot conditions for the CA and DF-2 fuels are significantly different than the trends for the remaining two fuels. The average indeno(1,2,3-cd)pyrene for the CA and DF-2 fuels at the Pilot A condition are significantly different than the ADMM15 and FT-100 fuels.



CONCLUSION: The average indeno(1,2,3-cd)pyrene at the Pilot A condition for mode 10 is significantly different than mode 11.



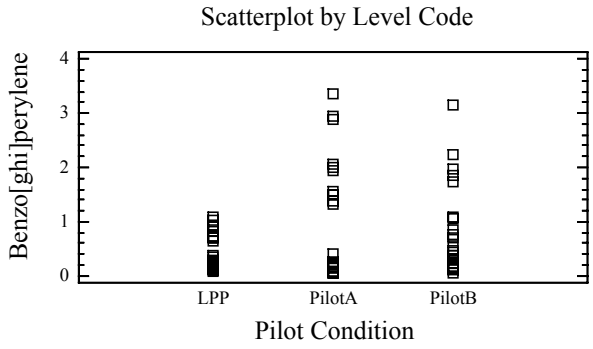
CONCLUSION: There is no significant interaction in the average indeno(1,2,3-cd)pyrene among the fuel and mode combinations.

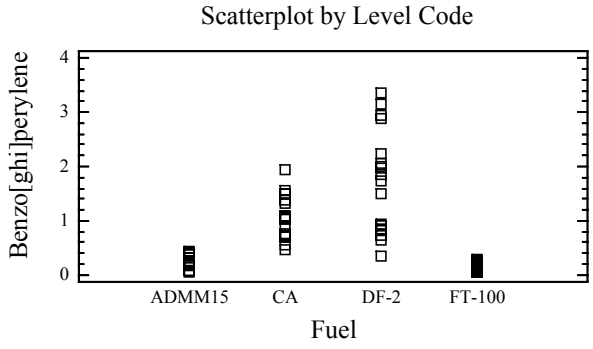
Multifactor ANOVA - Benzo[ghi]perylene (µg/kW-hr) Soluble PAH
Three Pilot Conditions on Four Fuels Modes 10 and 11

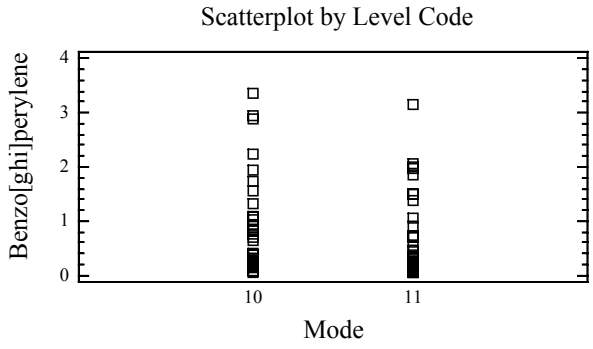
Analysis Summary

Dependent variable: benzogpe
Factors:
COND
FUEL
MODE

Number of complete cases: 71







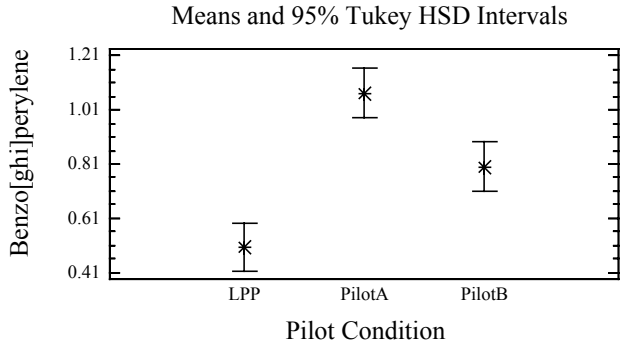
Analysis of Variance for benzogpe - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:COND	3.76493	2	1.88247	28.05	0.0000
B:FUEL	29.0105	3	9.67015	144.11	0.0000
C:MODE	0.320197	1	0.320197	4.77	0.0340

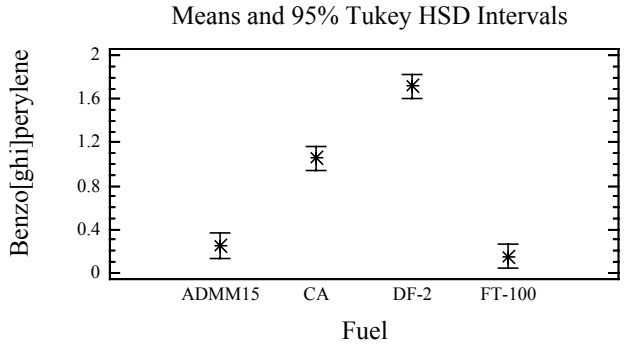
INTERACTIONS					
AB	7.55969	6	1.25995	18.78	0.0000
AC	0.850042	2	0.425021	6.33	0.0037
BC	0.0839346	3	0.0279782	0.42	0.7416
ABC	1.9744	6	0.329066	4.90	0.0006
RESIDUAL	3.15374	47	0.0671009		
TOTAL (CORRECTED)	46.9949	70			

All F-ratios are based on the residual mean square error.

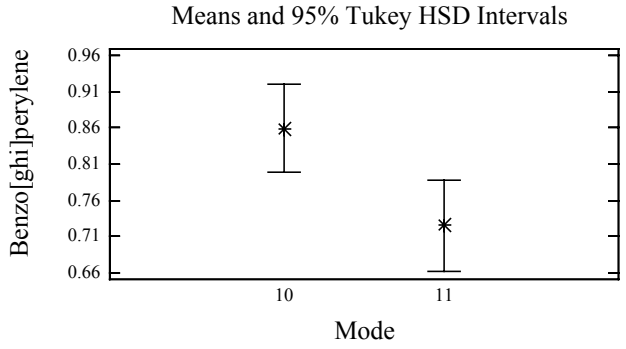
CONCLUSION: Statistically significant differences in the average benzo[ghi]perylene among the pilot conditions, fuels, modes, pilot condition*fuel interaction, pilot condition*mode interaction, and the three-factor interaction pilot condition*fuel*mode.



CONCLUSION: The average benzo[ghi]perylene for the three pilot conditions are significantly different from one another.



CONCLUSION: The average benzo[ghi]perylene for the DF-2 and CA fuels are significantly different from one another and the remaining two fuels. The average benzo[ghi]perylene for the FT-100 and ADMM15 fuels are not significantly different from one another.



CONCLUSION: The average benzo[ghi]perylene for mode 10 is significantly different than mode 11.

Multiple Range Tests for benzogpe by COND

Method: 95.0 percent Tukey HSD			
COND	Count	LS Mean	Homogeneous Groups
LPP	24	0.503794	X
PilotB	24	0.800707	X
PilotA	23	1.07206	X

Contrast	Difference	+/- Limits
LPP - PilotA	*-0.568266	0.18295
LPP - PilotB	*-0.296914	0.180993
PilotA - PilotB	*0.271352	0.18295

* denotes a statistically significant difference.

Multiple Range Tests for benzogpe by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	18	0.148796	X
ADMM15	17	0.248311	X
CA	18	1.0539	X
DF-2	18	1.71774	X

Contrast	Difference	+/- Limits
ADMM15 - CA	*-0.805591	0.233348
ADMM15 - DF-2	*-1.46943	0.233348
ADMM15 - FT-100	0.0995153	0.233348
CA - DF-2	*-0.663836	0.22999
CA - FT-100	*0.905106	0.22999
DF-2 - FT-100	*1.56894	0.22999

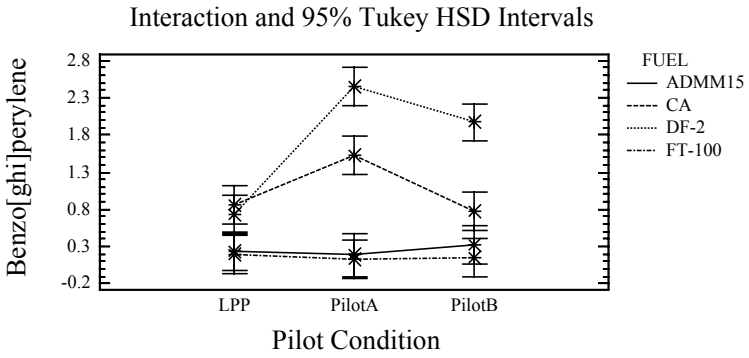
* denotes a statistically significant difference.

Multiple Range Tests for benzogpe by MODE

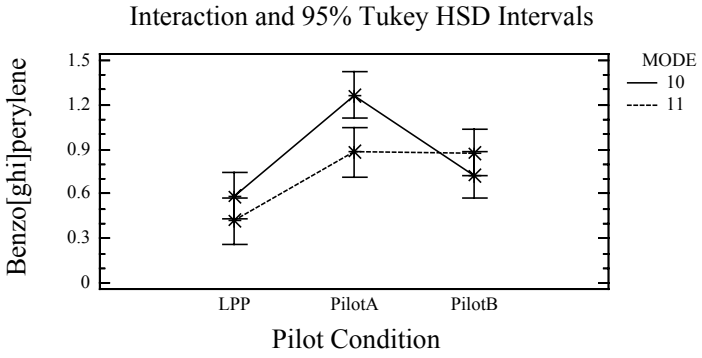
Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
11	35	0.724809	X
10	36	0.859565	X

Contrast	Difference	+/- Limits
10 - 11	*0.134757	0.123703

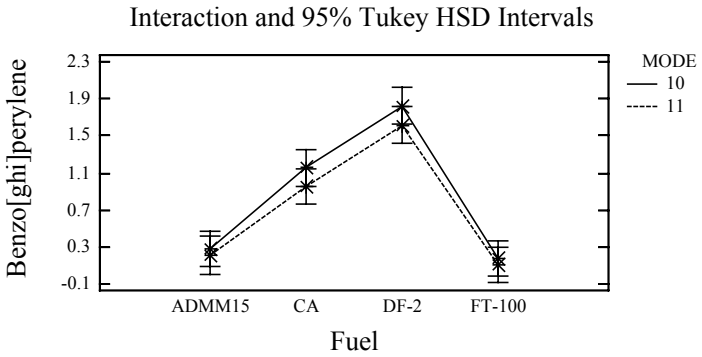
* denotes a statistically significant difference.



CONCLUSION: The trends in the average benzo[ghi]perylene across the pilot conditions for the DF-2 and CA fuels are significantly different than the trends for the remaining two fuels. The average benzo[ghi]perylene for the CA and DF-2 fuels at the Pilot A condition are significantly different than the ADMM15 and FT-100 fuels.



CONCLUSION: The average benzo[ghi]perylene at the Pilot A condition for mode 10 is significantly different than mode 11.



CONCLUSION: There is no significant interaction in the average benzo[ghi]perylene among the fuel and mode combinations.

APPENDIX G

ANOVA for MODE 12

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Total Particulates G-3
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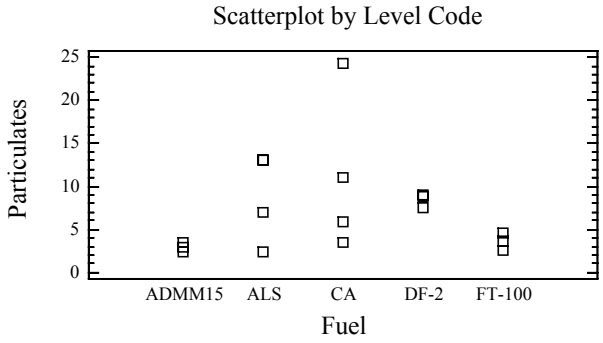
Multifactor ANOVA - Total Particulates (g/kW-hr)
LPP Only Mode 12
Analysis Summary

Dependent variable: PARTIC
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 17

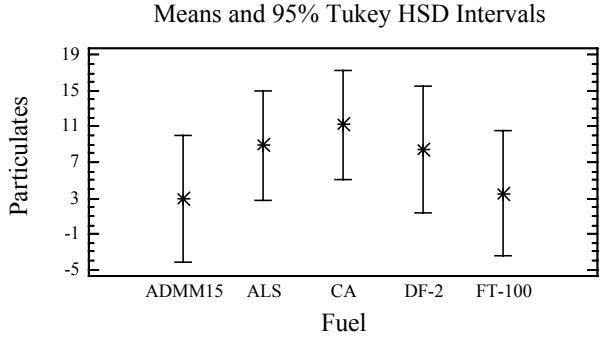


Analysis of Variance for PARTIC - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	173.578	4	43.3945	1.50	0.2645
RESIDUAL	348.132	12	29.011		
TOTAL (CORRECTED)	521.71	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average particulates among the fuels.



CONCLUSION: No statistically significant differences in the average particulates among the fuels.

Multiple Range Tests for PARTIC by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	3	2.90331	X
FT-100	3	3.54611	X

DF-2	3	8.41804	X
ALS	4	8.86013	X
CA	4	11.168	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-5.95682	13.1343
ADMM15 - CA	-8.26472	13.1343
ADMM15 - DF-2	-5.51473	14.0411
ADMM15 - FT-100	-0.642796	14.0411
ALS - CA	-2.3079	12.16
ALS - DF-2	0.44209	13.1343
ALS - FT-100	5.31402	13.1343
CA - DF-2	2.74999	13.1343
CA - FT-100	7.62192	13.1343
DF-2 - FT-100	4.87193	14.0411

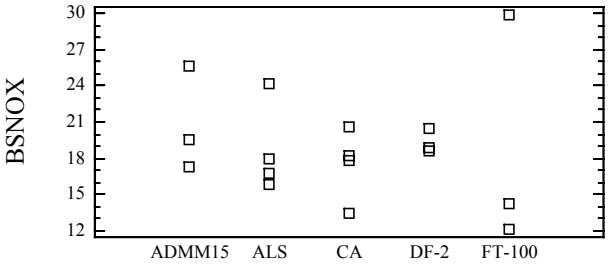
* denotes a statistically significant difference.

Multifactor ANOVA - BSNOX (g/kW-hr)
LPP Only Mode 12
Analysis Summary

Dependent variable: BSNOX
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 17

Scatterplot by Level Code



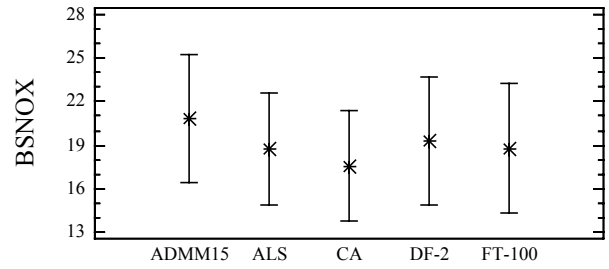
Analysis of Variance for BSNOX - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	19.5585	4	4.88963	0.20	0.9353
RESIDUAL	298.211	12	24.8509		
TOTAL (CORRECTED)	317.769	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSNOX among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differences in the average BSNOX among the fuels.

Multiple Range Tests for BSNOX by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
CA	4	17.5372	X

ALS	4	18.714	X
FT-100	3	18.7832	X
DF-2	3	19.3197	X
ADMM15	3	20.8529	X

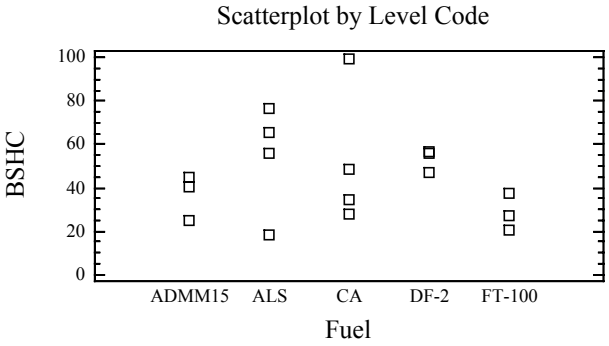
Contrast	Difference	+/- Limits
ADMM15 - ALS	2.13893	12.1561
ADMM15 - CA	3.31568	12.1561
ADMM15 - DF-2	1.53323	12.9955
ADMM15 - FT-100	2.06964	12.9955
ALS - CA	1.17675	11.2544
ALS - DF-2	-0.605695	12.1561
ALS - FT-100	-0.0692861	12.1561
CA - DF-2	-1.78244	12.1561
CA - FT-100	-1.24603	12.1561
DF-2 - FT-100	0.536409	12.9955

* denotes a statistically significant difference.

Multifactor ANOVA - BSHC (g/kW-hr)
LPP Only Mode 12
Analysis Summary

Dependent variable: BSHC
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 17

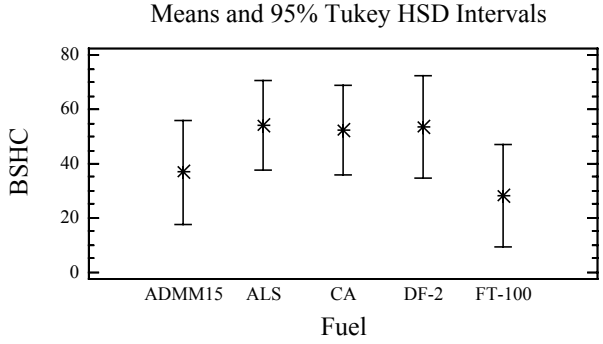


Analysis of Variance for BSHC - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1799.42	4	449.854	0.99	0.4499
RESIDUAL	5456.05	12	454.671		
TOTAL (CORRECTED)	7255.47	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSHC among the fuels.



CONCLUSION: No statistically significant differences in the average BSHC among the fuels.

Multiple Range Tests for BSHC by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups

FT-100	3	28.1695	X
ADMM15	3	36.7632	X
CA	4	52.4152	X
DF-2	3	53.3986	X
ALS	4	54.0764	X

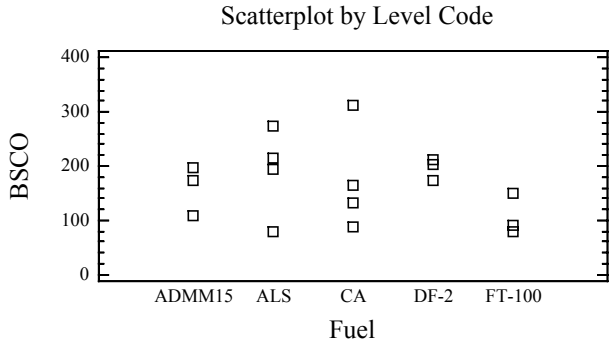
Contrast	Difference	+/- Limits
ADMM15 - ALS	-17.3132	51.9964
ADMM15 - CA	-15.652	51.9964
ADMM15 - DF-2	-16.6354	55.5865
ADMM15 - FT-100	8.59372	55.5865
ALS - CA	1.66119	48.1393
ALS - DF-2	0.677775	51.9964
ALS - FT-100	25.9069	51.9964
CA - DF-2	-0.983416	51.9964
CA - FT-100	24.2457	51.9964
DF-2 - FT-100	25.2291	55.5865

* denotes a statistically significant difference.

Multifactor ANOVA - BSCO (g/kW-hr)
LPP Only Mode 12
Analysis Summary

Dependent variable: BSCO
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 17

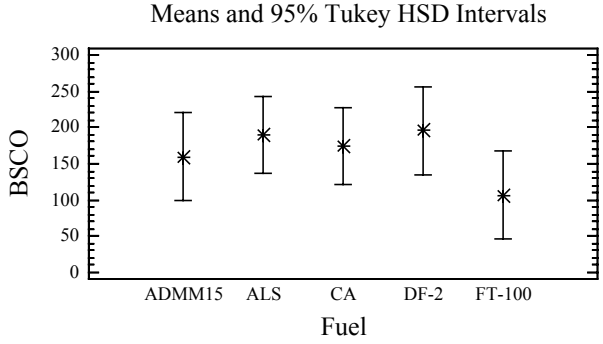


Analysis of Variance for BSCO - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	16190.3	4	4047.57	0.86	0.5157
RESIDUAL	56565.5	12	4713.8		
TOTAL (CORRECTED)	72755.8	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSCO among the fuels.



CONCLUSION: No statistically significant differences in the average BSCO among the fuels.

Multiple Range Tests for BSCO by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	106.035	X
ADMM15	3	159.445	X
CA	4	174.056	X
ALS	4	190.488	X
DF-2	3	195.655	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-31.0427	167.421
ADMM15 - CA	-14.6106	167.421
ADMM15 - DF-2	-36.2097	178.98
ADMM15 - FT-100	53.4104	178.98
ALS - CA	16.4321	155.002
ALS - DF-2	-5.16696	167.421
ALS - FT-100	84.4531	167.421
CA - DF-2	-21.5991	167.421
CA - FT-100	68.021	167.421
DF-2 - FT-100	89.62	178.98

* denotes a statistically significant difference.

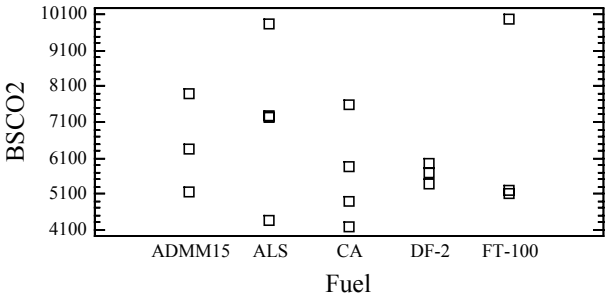
Multifactor ANOVA - BSCO2 (g/kW-hr)
LPP Only Mode 12

Analysis Summary

Dependent variable: BSCO2
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 17

Scatterplot by Level Code



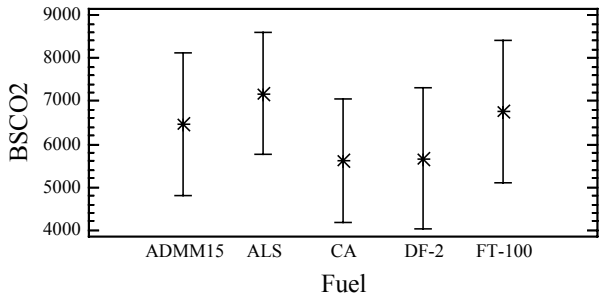
Analysis of Variance for BSCO2 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	6.79414E6	4	1.69854E6	0.49	0.7406
RESIDUAL	4.12673E7	12	3.43894E6		
TOTAL (CORRECTED)	4.80614E7	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSCO2 among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differences in the average BSCO2 among the fuels.

Multiple Range Tests for BSCO2 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups

CA	4	5618.38	X
DF-2	3	5664.79	X
ADMM15	3	6464.75	X
FT-100	3	6754.19	X
ALS	4	7174.0	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-709.244	4522.06
ADMM15 - CA	846.375	4522.06
ADMM15 - DF-2	799.964	4834.29
ADMM15 - FT-100	-289.437	4834.29
ALS - CA	1555.62	4186.62
ALS - DF-2	1509.21	4522.06
ALS - FT-100	419.807	4522.06
CA - DF-2	-46.4105	4522.06
CA - FT-100	-1135.81	4522.06
DF-2 - FT-100	-1089.4	4834.29

* denotes a statistically significant difference.

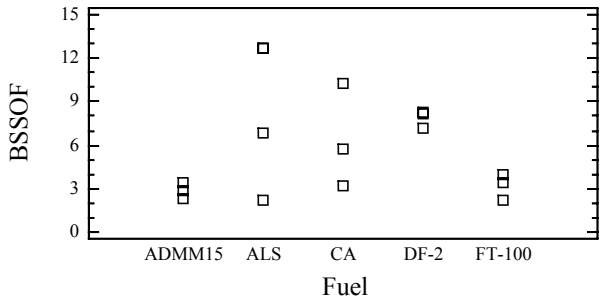
Multifactor ANOVA - BSSOF (g/kW-hr)
LPP Only Mode 12

Analysis Summary

Dependent variable: bssof
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



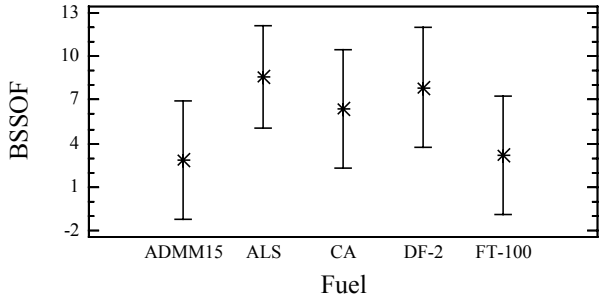
Analysis of Variance for bssof - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	91.9437	4	22.9859	2.37	0.1165
RESIDUAL	106.826	11	9.71143		
TOTAL (CORRECTED)	198.769	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSSOF among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differences in the average BSSOF among the fuels.

Multiple Range Tests for bssof by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups

ADMM15	3	2.83784	X
FT-100	3	3.16754	X
CA	3	6.36478	X
DF-2	3	7.86606	X
ALS	4	8.60195	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-5.76411	7.70442
ADMM15 - CA	-3.52694	8.23638
ADMM15 - DF-2	-5.02821	8.23638
ADMM15 - FT-100	-0.329696	8.23638
ALS - CA	2.23717	7.70442
ALS - DF-2	0.735895	7.70442
ALS - FT-100	5.43441	7.70442
CA - DF-2	-1.50128	8.23638
CA - FT-100	3.19724	8.23638
DF-2 - FT-100	4.69852	8.23638

* denotes a statistically significant difference.

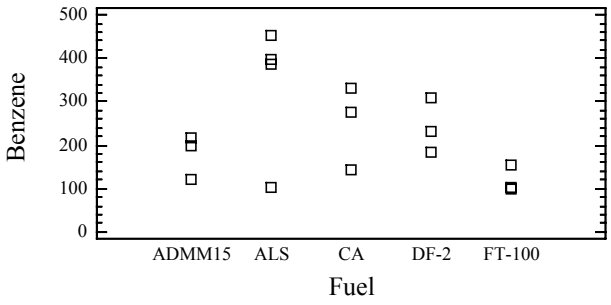
Multifactor ANOVA - Benzene (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Mode 12

Analysis Summary

Dependent variable: BENZENE
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



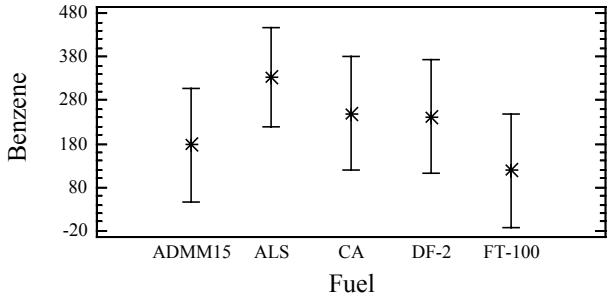
Analysis of Variance for BENZENE - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	90429.9	4	22607.5	2.31	0.1230
RESIDUAL	107777.0	11	9797.87		
TOTAL (CORRECTED)	198206.0	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average benzene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differences in the average benzene among the fuels.

Multiple Range Tests for BENZENE by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	117.955	X
ADMM15	3	178.153	X
DF-2	3	241.471	X
CA	3	249.61	X
ALS	4	333.891	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-155.738	244.717
ADMM15 - CA	-71.4565	261.614
ADMM15 - DF-2	-63.3182	261.614
ADMM15 - FT-100	60.198	261.614
ALS - CA	84.2815	244.717
ALS - DF-2	92.4198	244.717
ALS - FT-100	215.936	244.717
CA - DF-2	8.13835	261.614
CA - FT-100	131.654	261.614
DF-2 - FT-100	123.516	261.614

* denotes a statistically significant difference.

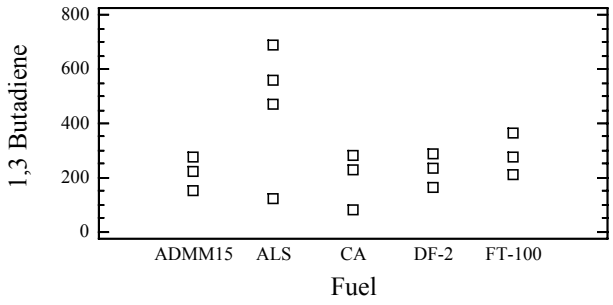
Multifactor ANOVA - 1,3 Butadiene (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Mode 12

Analysis Summary

Dependent variable: BUTAD
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



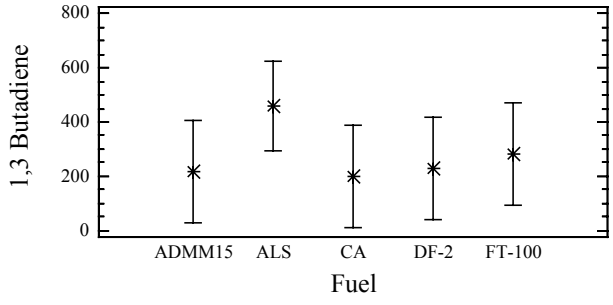
Analysis of Variance for BUTAD - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	169229.0	4	42307.4	2.06	0.1547
RESIDUAL	225726.0	11	20520.5		
TOTAL (CORRECTED)	394955.0	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average 1,3 Butadiene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differences in the average 1,3 Butadiene among the fuels.

Multiple Range Tests for BUTAD by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
CA	3	196.865	X
ADMM15	3	216.494	X
DF-2	3	229.33	X
FT-100	3	282.903	X
ALS	4	460.173	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-243.679	354.155
ADMM15 - CA	19.6288	378.607
ADMM15 - DF-2	-12.8365	378.607
ADMM15 - FT-100	-66.4091	378.607
ALS - CA	263.308	354.155
ALS - DF-2	230.843	354.155
ALS - FT-100	177.27	354.155
CA - DF-2	-32.4653	378.607
CA - FT-100	-86.0379	378.607
DF-2 - FT-100	-53.5726	378.607

* denotes a statistically significant difference.

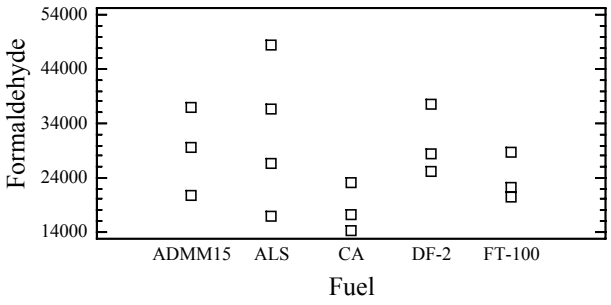
Multifactor ANOVA - Formaldehyde (mg/kW-hr) Toxic Gaseous Emissions
LPP Only Mode 12

Analysis Summary

Dependent variable: FORMALD
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



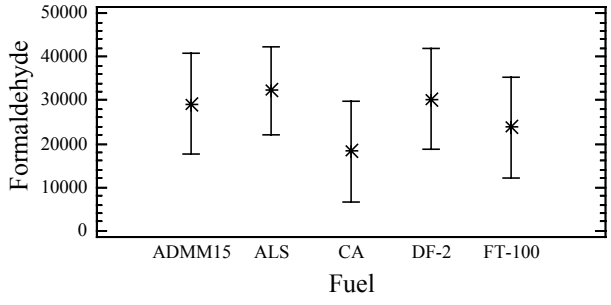
Analysis of Variance for FORMALD - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	4.23523E8	4	1.05881E8	1.38	0.3020
RESIDUAL	8.41735E8	11	7.65213E7		
TOTAL (CORRECTED)	1.26526E9	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average formaldehyde among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differences in the average formaldehyde among the fuels.

Multiple Range Tests for FORMALD by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
CA	3	18177.0	X
FT-100	3	23723.0	X
ADMM15	3	29186.9	X
DF-2	3	30348.2	X
ALS	4	32241.5	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-3054.63	21626.7
ADMM15 - CA	11009.9	23119.9
ADMM15 - DF-2	-1161.35	23119.9
ADMM15 - FT-100	5463.88	23119.9
ALS - CA	14064.5	21626.7
ALS - DF-2	1893.28	21626.7
ALS - FT-100	8518.5	21626.7
CA - DF-2	-12171.2	23119.9
CA - FT-100	-5545.99	23119.9
DF-2 - FT-100	6625.22	23119.9

* denotes a statistically significant difference.

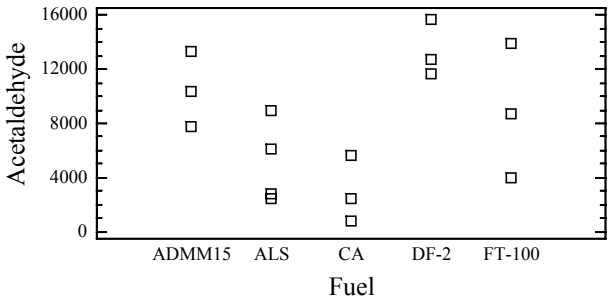
Multifactor ANOVA - Acetaldehyde (mg/Kw-hr) Toxic Gaseous Emissions
LPP Only Mode 12

Analysis Summary

Dependent variable: ACETALD
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



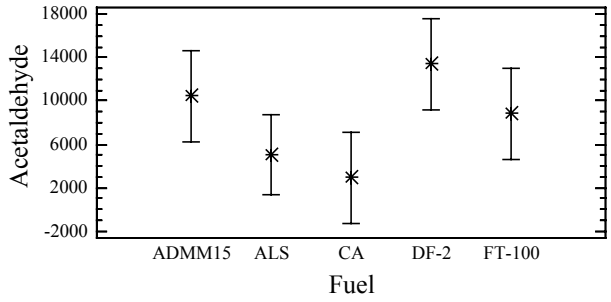
Analysis of Variance for ACETALD - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	2.19352E8	4	5.48381E7	5.37	0.0121
RESIDUAL	1.12414E8	11	1.02195E7		
TOTAL (CORRECTED)	3.31766E8	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average acetaldehyde among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average acetaldehyde for the DF-2 fuel is significantly different than the ALS and CA fuels.

Multiple Range Tests for ACETALD by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
CA	3	2928.49	X
ALS	4	5079.77	X
FT-100	3	8856.78	XX
ADMM15	3	10477.5	XX
DF-2	3	13400.4	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	5397.77	7903.37
ADMM15 - CA	7549.06	8449.06
ADMM15 - DF-2	-2922.88	8449.06
ADMM15 - FT-100	1620.77	8449.06
ALS - CA	2151.28	7903.37
ALS - DF-2	*-8320.65	7903.37
ALS - FT-100	-3777.01	7903.37
CA - DF-2	*-10471.9	8449.06
CA - FT-100	-5928.29	8449.06
DF-2 - FT-100	4543.65	8449.06

* denotes a statistically significant difference.

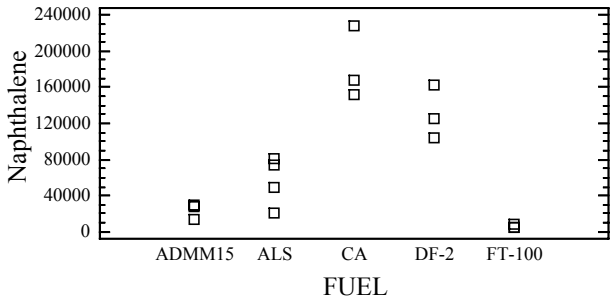
Multifactor ANOVA - Naphthalene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: GNAPHTH
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



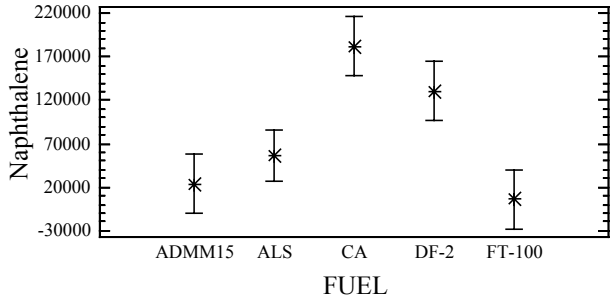
Analysis of Variance for GNAPHTH - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	6.71331E10	4	1.67833E10	25.16	0.0000
RESIDUAL	7.33698E9	11	6.66998E8		
TOTAL (CORRECTED)	7.44701E10	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average naphthalene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: There are two distinct fuel groupings with respect to the average naphthalene. The DF-2 and CA fuels are not significantly different from one another but are significantly different from the remaining three fuels. The ALS, ADMM15, and FT-100 fuels are not significantly different from one another, but are significantly different from the remaining two fuels.

Multiple Range Tests for GNAPHTH by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	6057.98	X
ADMM15	3	23712.5	X
ALS	4	56373.7	X
DF-2	3	130839.0	X
CA	3	182116.0	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-32661.2	63850.0
ADMM15 - CA	*-158403.0	68258.5
ADMM15 - DF-2	*-107126.0	68258.5
ADMM15 - FT-100	17654.5	68258.5
ALS - CA	*-125742.0	63850.0
ALS - DF-2	*-74465.1	63850.0
ALS - FT-100	50315.7	63850.0
CA - DF-2	51276.7	68258.5
CA - FT-100	*176058.0	68258.5
DF-2 - FT-100	*124781.0	68258.5

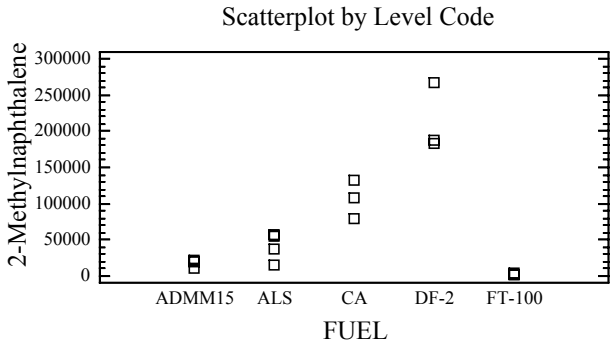
* denotes a statistically significant difference.

Multifactor ANOVA - 2-Methylnaphthalene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: METHYL2
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

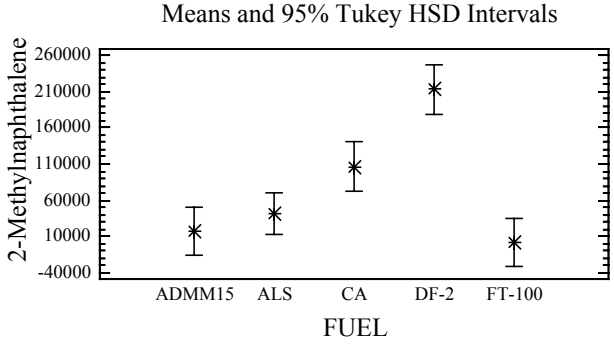


Analysis of Variance for METHYL2 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	9.06153E10	4	2.26538E10	35.30	0.0000
RESIDUAL	7.05945E9	11	6.41768E8		
TOTAL (CORRECTED)	9.76748E10	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistiaclly significant differences in the average 2-methylnaphthalene among the fuels.



CONCLUSION: There are three distinct fuel groupings with respect to the average 2-methylnaphthalene. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly different from the remaining two fuels. The CA and DF-2 fuels are significantly different from one another and the remaining three fuels.

Multiple Range Tests for METHYL2 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	2255.56	X
ADMM15	3	17201.2	X
ALS	4	40670.6	X
CA	3	106437.0	X
DF-2	3	212921.0	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-23469.4	62630.8
ADMM15 - CA	*-89235.8	66955.1
ADMM15 - DF-2	*-195719.0	66955.1
ADMM15 - FT-100	14945.6	66955.1
ALS - CA	*-65766.4	62630.8
ALS - DF-2	*-172250.0	62630.8
ALS - FT-100	38415.1	62630.8
CA - DF-2	*-106484.0	66955.1
CA - FT-100	*104181.0	66955.1
DF-2 - FT-100	*210665.0	66955.1

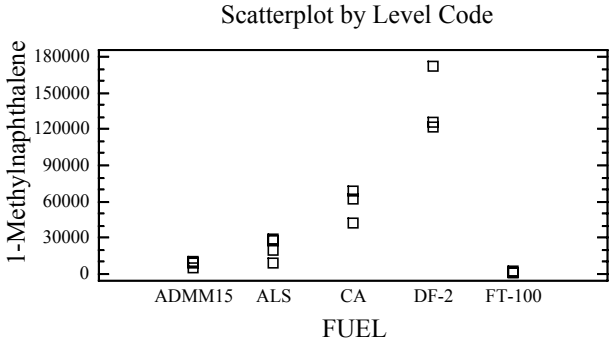
* denotes a statistically significant difference.

Multifactor ANOVA - 1-Methylnaphthalene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: METHYL1
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

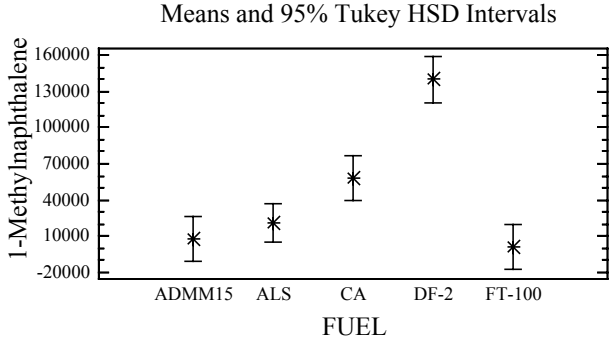


Analysis of Variance for METHYL1 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	3.95519E10	4	9.88796E9	49.21	0.0000
RESIDUAL	2.21039E9	11	2.00944E8		
TOTAL (CORRECTED)	4.17622E10	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average 1-methylnaphthalene among the fuels.



CONCLUSION: There are three distinct fuel groupings with respect to the average 1-methylnaphthalene. The FT-100, ADMM15, and ALS fuels are not significantly different from one another, but are significantly different from the remaining two fuels. The CA and DF-2 fuels are significantly different from one another and the remaining three fuels.

Multiple Range Tests for METHYL1 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	1428.58	X
ADMM15	3	8078.03	X
ALS	4	21017.6	X
CA	3	57939.9	X
DF-2	3	139827.0	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-12939.5	35045.8
ADMM15 - CA	*-49861.8	37465.6
ADMM15 - DF-2	*-131749.0	37465.6
ADMM15 - FT-100	6649.44	37465.6
ALS - CA	*-36922.3	35045.8
ALS - DF-2	*-118809.0	35045.8
ALS - FT-100	19589.0	35045.8
CA - DF-2	*-81886.7	37465.6
CA - FT-100	*56511.3	37465.6
DF-2 - FT-100	*138398.0	37465.6

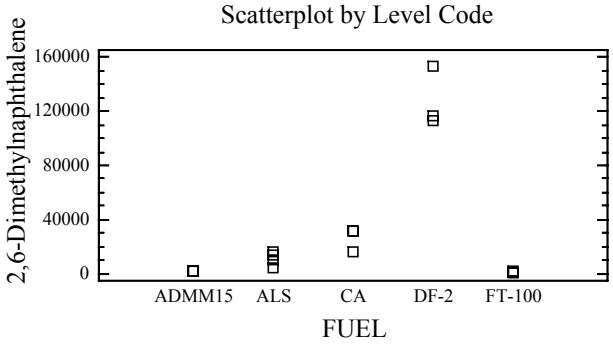
* denotes a statistically significant difference.

Multifactor ANOVA - 2,6-Dimethylnaphthalene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: DIMETHYL
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

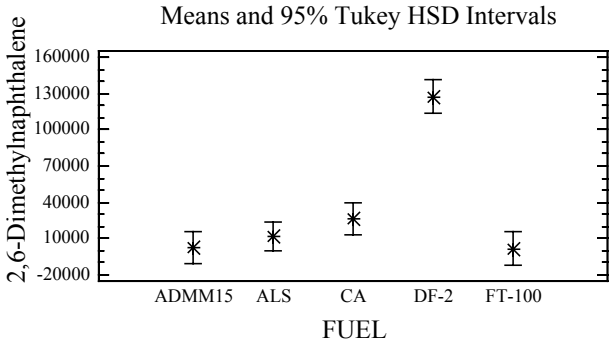


Analysis of Variance for DIMETHYL - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	3.47244E10	4	8.68109E9	82.28	0.0000
RESIDUAL	1.16051E9	11	1.05501E8		
TOTAL (CORRECTED)	3.58849E10	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average 2,6-dimethylnaphthalene among the fuels.



CONCLUSION: The average 2,6-dimethylnaphthalene for the DF-2 fuel is significantly different than the remaining four fuels. The average 2,6-dimethylnaphthalene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for DIMETHYL by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	1362.24	X
ADMM15	3	2047.66	X
ALS	4	11261.4	X
CA	3	26261.0	X
DF-2	3	127567.0	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-9213.7	25393.8
ADMM15 - CA	-24213.3	27147.1
ADMM15 - DF-2	*-125519.0	27147.1
ADMM15 - FT-100	685.424	27147.1
ALS - CA	-14999.6	25393.8
ALS - DF-2	*-116306.0	25393.8
ALS - FT-100	9899.13	25393.8
CA - DF-2	*-101306.0	27147.1
CA - FT-100	24898.8	27147.1
DF-2 - FT-100	*126205.0	27147.1

* denotes a statistically significant difference.

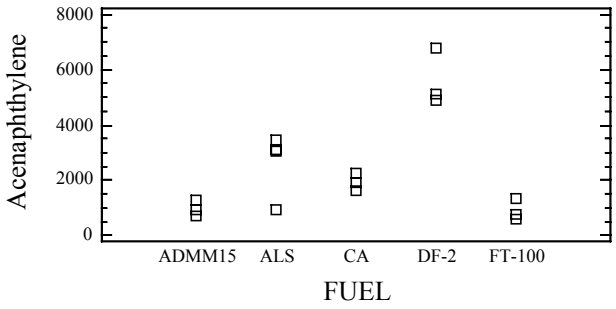
Multifactor ANOVA - Acenaphthylene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: GACENAPH
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



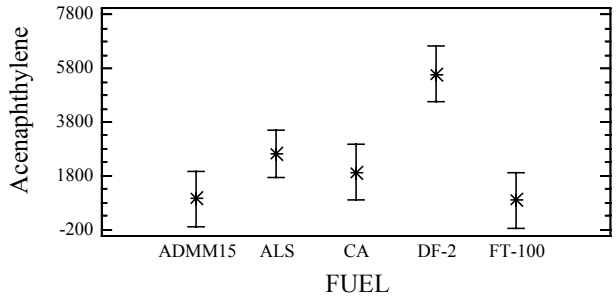
Analysis of Variance for GACENAPH - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	4.45816E7	4	1.11454E7	18.31	0.0001
RESIDUAL	6.69741E6	11	608855.0		
TOTAL (CORRECTED)	5.1279E7	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average acenaphthylene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average acenaphthylene for the DF-2 fuel is significantly different than the remaining four fuels. The average acenaphthylene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for GACENAPH by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	888.181	X
ADMM15	3	953.779	X
CA	3	1925.62	X
ALS	4	2638.22	X
DF-2	3	5591.2	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1684.44	1929.1
ADMM15 - CA	-971.841	2062.3
ADMM15 - DF-2	*-4637.42	2062.3
ADMM15 - FT-100	65.5985	2062.3
ALS - CA	712.6	1929.1
ALS - DF-2	*-2952.98	1929.1
ALS - FT-100	1750.04	1929.1
CA - DF-2	*-3665.58	2062.3
CA - FT-100	1037.44	2062.3
DF-2 - FT-100	*4703.02	2062.3

* denotes a statistically significant difference.

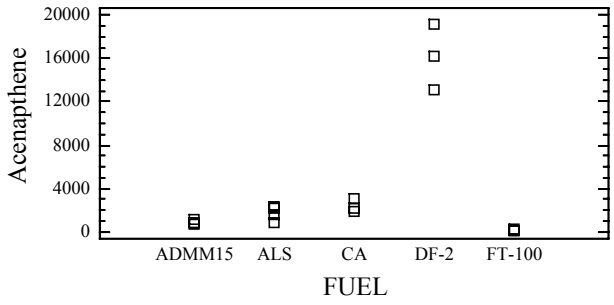
Multifactor ANOVA - Acenaphthene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: ACENAPTH
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



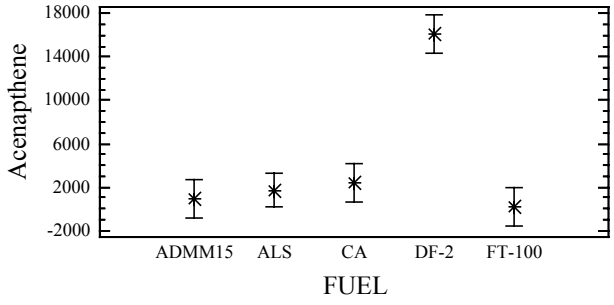
Analysis of Variance for ACENAPTH - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	5.40536E8	4	1.35134E8	72.59	0.0000
RESIDUAL	2.04774E7	11	1.86158E6		
TOTAL (CORRECTED)	5.61013E8	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average acenaphthene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average acenaphthene for the DF-2 fuel is significantly different than the remaining four fuels. The average acenaphthene for the FT-100, ADMM15, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for ACENAPTH by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	195.774	X
ADMM15	3	907.615	X
ALS	4	1706.53	X
CA	3	2385.88	X
DF-2	3	16107.0	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-798.92	3373.18
ADMM15 - CA	-1478.26	3606.08
ADMM15 - DF-2	*-15199.4	3606.08
ADMM15 - FT-100	711.84	3606.08
ALS - CA	-679.344	3373.18
ALS - DF-2	*-14400.5	3373.18
ALS - FT-100	1510.76	3373.18
CA - DF-2	*-13721.1	3606.08
CA - FT-100	2190.1	3606.08
DF-2 - FT-100	*15911.2	3606.08

* denotes a statistically significant difference.

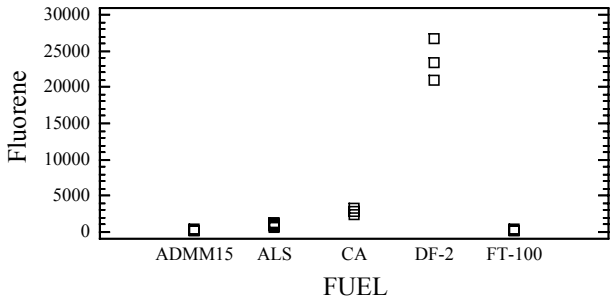
Multifactor ANOVA - Fluorene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: GFLUOREN
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



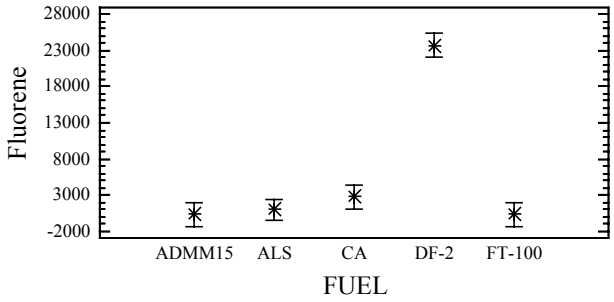
Analysis of Variance for GFLUOREN - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1.25657E9	4	3.14143E8	194.31	0.0000
RESIDUAL	1.77834E7	11	1.61668E6		
TOTAL (CORRECTED)	1.27436E9	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average fluorene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average fluorene for the DF-2 fuel is significantly different than the remaining four fuels. The average fluorene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for GFLUOREN by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	3	296.702	X
FT-100	3	305.082	X
ALS	4	939.148	X
CA	3	2767.23	X
DF-2	3	23660.4	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-642.446	3143.48
ADMM15 - CA	-2470.53	3360.52
ADMM15 - DF-2	*-23363.7	3360.52
ADMM15 - FT-100	-8.3802	3360.52
ALS - CA	-1828.08	3143.48
ALS - DF-2	*-22721.3	3143.48
ALS - FT-100	634.066	3143.48
CA - DF-2	*-20893.2	3360.52
CA - FT-100	2462.15	3360.52
DF-2 - FT-100	*23355.3	3360.52

* denotes a statistically significant difference.

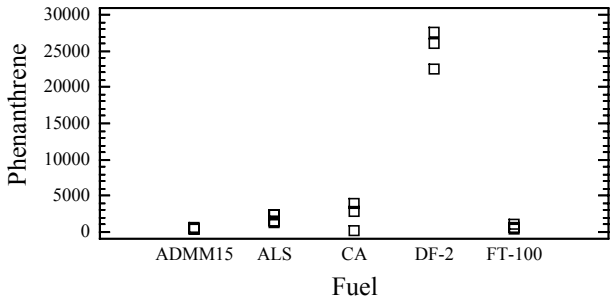
Multifactor ANOVA - Phenanthrene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: GPHENANT
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



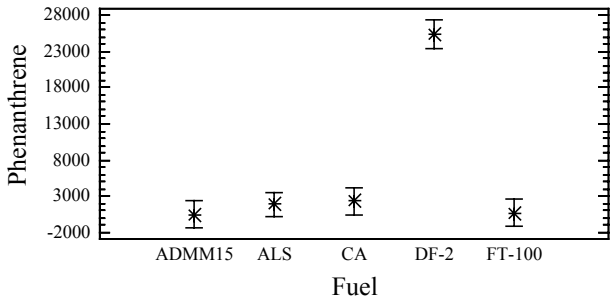
Analysis of Variance for GPHENANT - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1.41708E9	4	3.5427E8	168.73	0.0000
RESIDUAL	2.30963E7	11	2.09967E6		
TOTAL (CORRECTED)	1.44018E9	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average phenanthrene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average phenanthrene for the DF-2 fuel is significantly different than the remaining four fuels. The average phenanthrene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for GPHENANT by FUEL

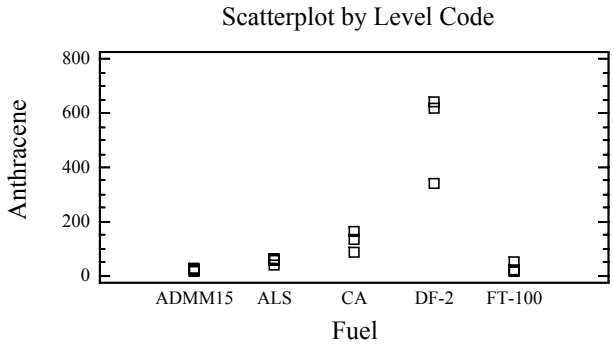
```
-------------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
FUEL           Count     LS Mean           Homogeneous Groups
-------------------------------------------------------------------------------
ADMM15         3         457.248           X
FT-100         3         699.826           X
ALS            4         1891.43           X
CA             3         2267.23           X
DF-2           3         25421.1            X
-------------------------------------------------------------------------------
Contrast                                 Difference           +/-  Limits
-------------------------------------------------------------------------------
ADMM15 - ALS                              -1434.18            3582.4
ADMM15 - CA                               -1809.99            3829.74
ADMM15 - DF-2                            *-24963.9            3829.74
ADMM15 - FT-100                           -242.578            3829.74
ALS - CA                                  -375.802            3582.4
ALS - DF-2                               *-23529.7            3582.4
ALS - FT-100                              1191.6              3582.4
CA - DF-2                                *-23153.9            3829.74
CA - FT-100                               1567.41             3829.74
DF-2 - FT-100                            *24721.3             3829.74
-------------------------------------------------------------------------------
* denotes a statistically significant difference.
```

Multifactor ANOVA - Anthracene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: GANTHR
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

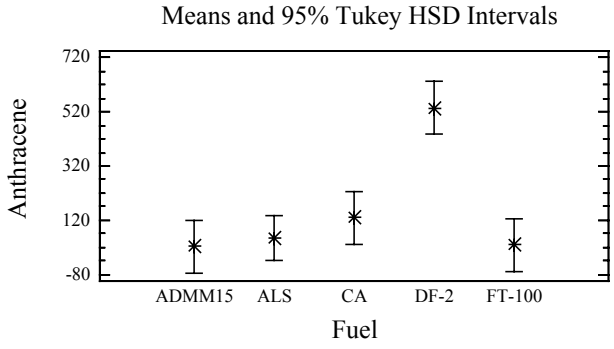


Analysis of Variance for GANTHR - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	570491.0	4	142623.0	26.36	0.0000
RESIDUAL	59515.0	11	5410.46		
TOTAL (CORRECTED)	630006.0	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average anthracene among the fuels.



CONCLUSION: The average anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The average anthracene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for GANTHR by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	3	22.3976	X
FT-100	3	29.4149	X
ALS	4	54.2201	X
CA	3	129.708	X
DF-2	3	533.053	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-31.8225	181.851
ADMM15 - CA	-107.311	194.407
ADMM15 - DF-2	*-510.655	194.407
ADMM15 - FT-100	-7.01737	194.407
ALS - CA	-75.4884	181.851
ALS - DF-2	*-478.833	181.851
ALS - FT-100	24.8052	181.851
CA - DF-2	*-403.344	194.407
CA - FT-100	100.294	194.407
DF-2 - FT-100	*503.638	194.407

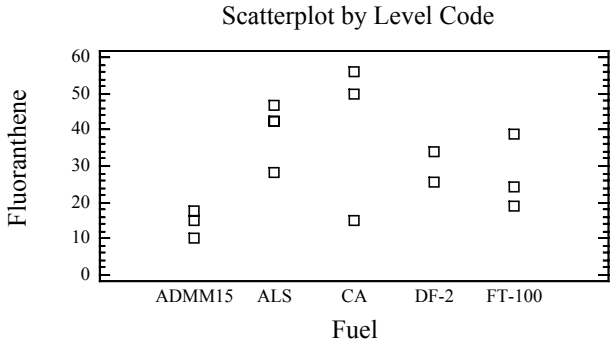
* denotes a statistically significant difference.

Multifactor ANOVA - Fluoranthene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: GFLUORAN
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 15

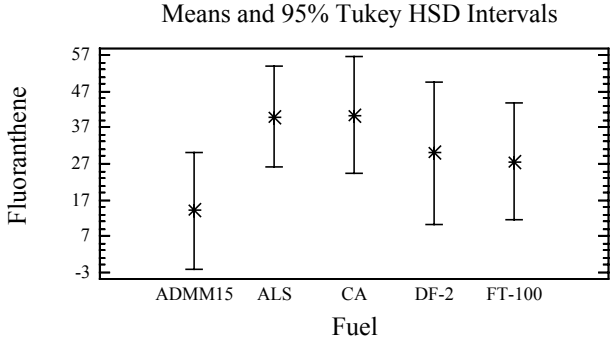


Analysis of Variance for GFLUORAN - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1489.76	4	372.439	2.57	0.1028
RESIDUAL	1447.56	10	144.756		
TOTAL (CORRECTED)	2937.32	14			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average fluoranthene among the fuels.



CONCLUSION: No statistically significant differences in the average fluoranthene among the fuels.

Multiple Range Tests for GFLUORAN by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	3	14.0387	X
FT-100	3	27.4609	X
DF-2	2	29.9511	X
ALS	4	39.9585	X
CA	3	40.4149	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-25.9198	30.245
ADMM15 - CA	-26.3762	32.3333
ADMM15 - DF-2	-15.9124	36.1497
ADMM15 - FT-100	-13.4222	32.3333
ALS - CA	-0.45635	30.245
ALS - DF-2	10.0074	34.2946
ALS - FT-100	12.4976	30.245
CA - DF-2	10.4638	36.1497
CA - FT-100	12.9539	32.3333
DF-2 - FT-100	2.49016	36.1497

* denotes a statistically significant difference.

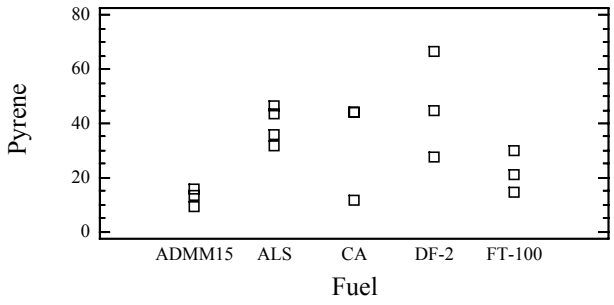
Multifactor ANOVA - Pyrene (µg/kW-hr) Gaseous PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: GPYRENE
Factors:
FUEL
Selection variable: MODE=12

Number of complete cases: 16

Scatterplot by Level Code



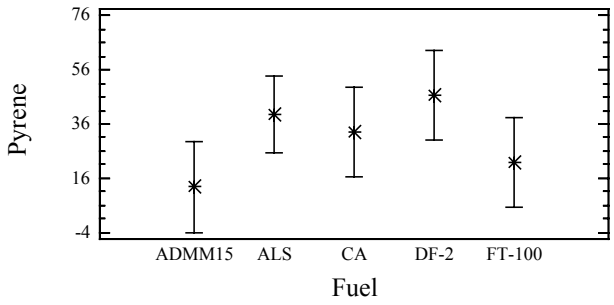
Analysis of Variance for GPYRENE - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	2271.39	4	567.846	3.61	0.0409
RESIDUAL	1728.66	11	157.15		
TOTAL (CORRECTED)	4000.04	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average pyrene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average pyrene for the DF-2 fuel is significantly different than the ADMM15 fuel.

Multiple Range Tests for GPYRENE by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	3	12.7041	X
FT-100	3	21.803	XX
CA	3	33.2915	XX
ALS	4	39.4763	XX
DF-2	3	46.4006	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-26.7722	30.9925
ADMM15 - CA	-20.5875	33.1324
ADMM15 - DF-2	*-33.6965	33.1324
ADMM15 - FT-100	-9.09893	33.1324
ALS - CA	6.18478	30.9925
ALS - DF-2	-6.92426	30.9925
ALS - FT-100	17.6733	30.9925
CA - DF-2	-13.109	33.1324
CA - FT-100	11.4885	33.1324
DF-2 - FT-100	24.5976	33.1324

* denotes a statistically significant difference.

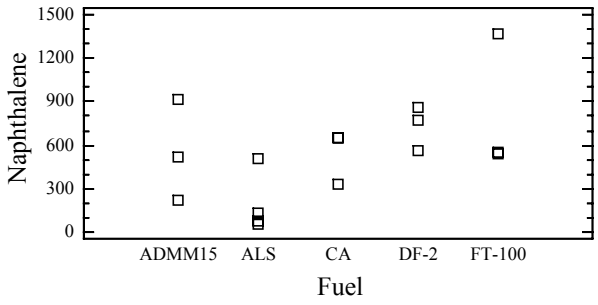
Multifactor ANOVA - Naphthalene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: naphth
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



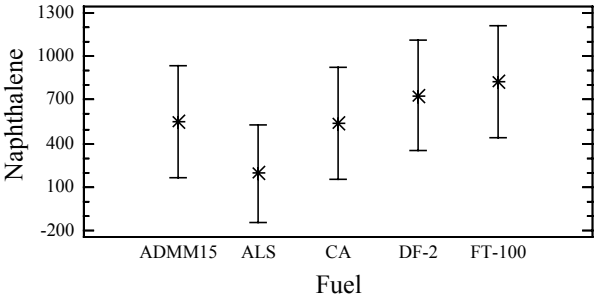
Analysis of Variance for naphth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	834111.0	4	208528.0	2.44	0.1094
RESIDUAL	941727.0	11	85611.6		
TOTAL (CORRECTED)	1.77584E6	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average naphthalene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differnces in the average naphthalene among the fuels.

Multiple Range Tests for naphth by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ALS	4	192.221	X
CA	3	541.585	X
ADMM15	3	553.687	X
DF-2	3	732.529	X
FT-100	3	822.211	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	361.466	723.377
ADMM15 - CA	12.1018	773.323
ADMM15 - DF-2	-178.842	773.323
ADMM15 - FT-100	-268.524	773.323
ALS - CA	-349.364	723.377
ALS - DF-2	-540.308	723.377
ALS - FT-100	-629.99	723.377
CA - DF-2	-190.943	773.323
CA - FT-100	-280.625	773.323
DF-2 - FT-100	-89.682	773.323

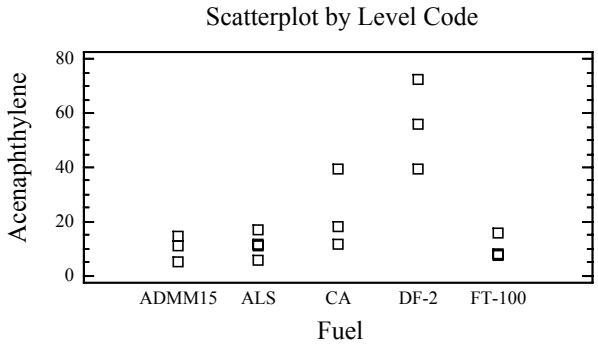
* denotes a statistically significant difference.

Multifactor ANOVA - Acenaphthylene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: acenaph
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

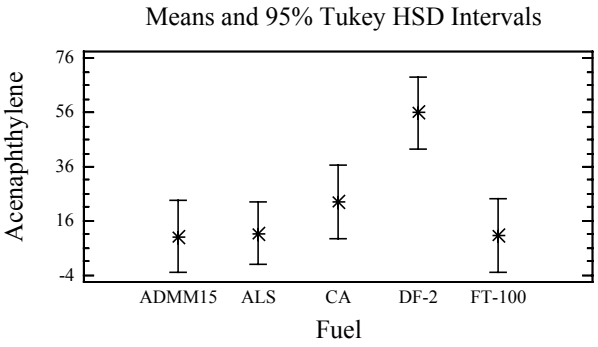


Analysis of Variance for acenaph - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	4687.94	4	1171.98	11.34	0.0007
RESIDUAL	1136.45	11	103.314		
TOTAL (CORRECTED)	5824.39	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average acenaphthylene among the fuels.



CONCLUSION: The average acenaphthylene for the DF-2 fuel is significantly different than the remaining four fuels. The average acenaphthylene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different.

Multiple Range Tests for acenaph by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	10.2537	X
FT-100	3	10.5474	X
ALS	4	11.3751	X
CA	3	23.1257	X
DF-2	3	55.8058	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-1.12136	25.1292
ADMM15 - CA	-12.872	26.8642
ADMM15 - DF-2	*-45.5521	26.8642
ADMM15 - FT-100	-0.293675	26.8642
ALS - CA	-11.7506	25.1292
ALS - DF-2	*-44.4307	25.1292
ALS - FT-100	0.827684	25.1292
CA - DF-2	*-32.6801	26.8642
CA - FT-100	12.5783	26.8642
DF-2 - FT-100	*45.2584	26.8642

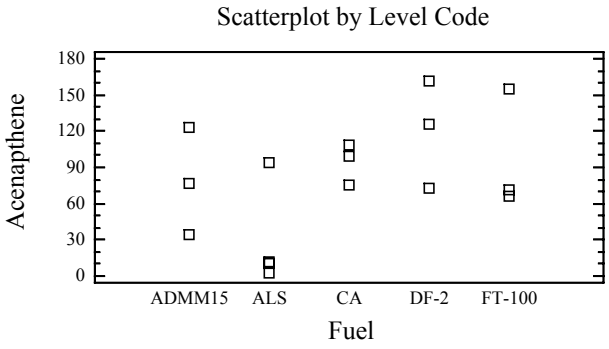
* denotes a statistically significant difference.

Multifactor ANOVA - Acenaphthene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: acenapth
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

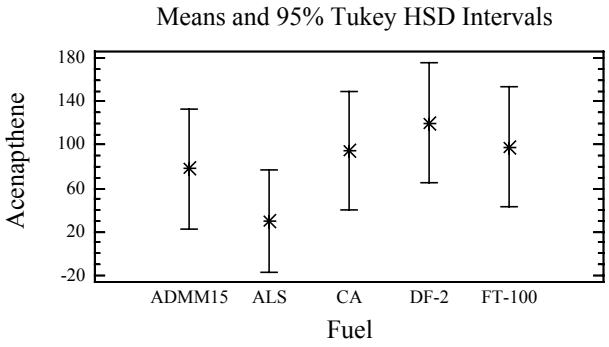


Analysis of Variance for acenapth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	16485.5	4	4121.37	2.36	0.1170
RESIDUAL	19189.6	11	1744.51		
TOTAL (CORRECTED)	35675.1	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average acenaphthene among the fuels.



CONCLUSION: No statistically significant differences in the average acenaphthene among the fuels.

Multiple Range Tests for acenapth by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ALS	4	29.8938	X
ADMM15	3	78.0651	X
CA	3	94.6604	X
FT-100	3	98.0092	X
DF-2	3	120.096	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	48.1713	103.261
ADMM15 - CA	-16.5953	110.39
ADMM15 - DF-2	-42.0307	110.39
ADMM15 - FT-100	-19.9441	110.39
ALS - CA	-64.7666	103.261
ALS - DF-2	-90.2021	103.261
ALS - FT-100	-68.1155	103.261
CA - DF-2	-25.4354	110.39
CA - FT-100	-3.34881	110.39
DF-2 - FT-100	22.0866	110.39

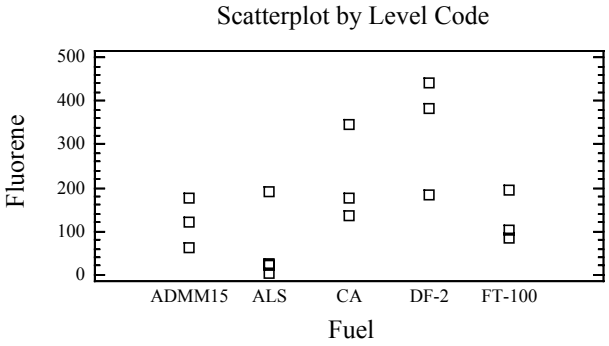
* denotes a statistically significant difference.

Multifactor ANOVA - Fluorene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: fluorene
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

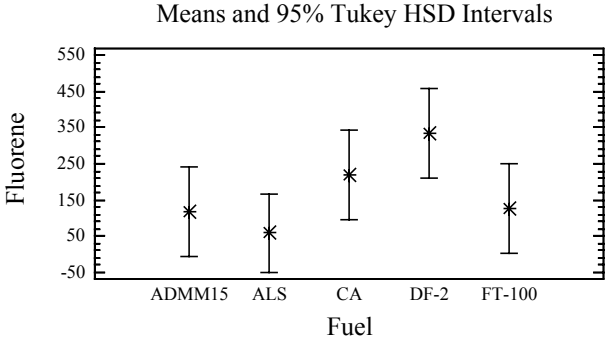


Analysis of Variance for fluorene - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	151451.0	4	37862.7	4.26	0.0254
RESIDUAL	97880.1	11	8898.19		
TOTAL (CORRECTED)	249331.0	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically signficant differences in the average fluorene among the fuels.



CONCLUSION: The average fluorene for the DF-2 fuel is significantly different than the ALS fuel.

Multiple Range Tests for fluorene by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ALS	4	59.0582	X
ADMM15	3	118.419	XX
FT-100	3	126.625	XX
CA	3	219.753	XX
DF-2	3	334.938	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	59.3603	233.211
ADMM15 - CA	-101.334	249.313
ADMM15 - DF-2	-216.519	249.313
ADMM15 - FT-100	-8.20674	249.313
ALS - CA	-160.695	233.211
ALS - DF-2	*-275.879	233.211
ALS - FT-100	-67.5671	233.211
CA - DF-2	-115.185	249.313
CA - FT-100	93.1275	249.313
DF-2 - FT-100	208.312	249.313

* denotes a statistically significant difference.

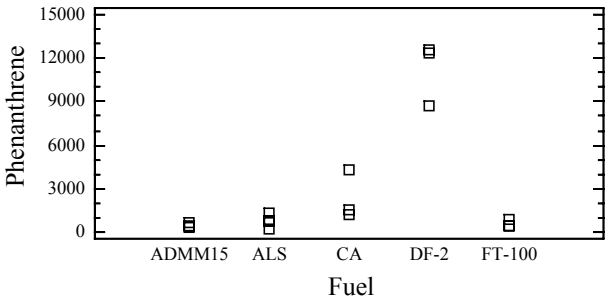
Multifactor ANOVA - Phenanthrene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: phenanth
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



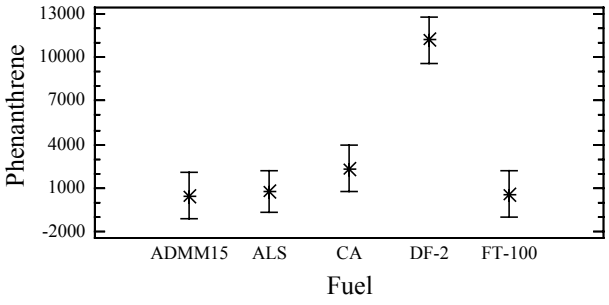
Analysis of Variance for phenanth - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	2.62026E8	4	6.55064E7	44.22	0.0000
RESIDUAL	1.62965E7	11	1.4815E6		
TOTAL (CORRECTED)	2.78322E8	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average phenanthrene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average phenanthrene for the DF-2 fuel is significantly different than the remaining four fuels. The average phenanthrene for the ADMM15, FT-100, ALS, and CA fuels are not significantly different from one another.

Multiple Range Tests for phenanth by fuel

```
---------------------------------------------------------------------------
Method: 95.0 percent Tukey HSD
fuel           Count     LS Mean           Homogeneous Groups
---------------------------------------------------------------------------
ADMM15         3         459.058           X
FT-100         3         572.378           X
ALS            4         736.461           X
CA             3         2331.39           X
DF-2           3         11230.9            X
---------------------------------------------------------------------------
Contrast                                  Difference           +/-  Limits
---------------------------------------------------------------------------
ADMM15 - ALS                              -277.403             3009.19
ADMM15 - CA                               -1872.33             3216.96
ADMM15 - DF-2                            *-10771.8             3216.96
ADMM15 - FT-100                           -113.32              3216.96
ALS - CA                                  -1594.93             3009.19
ALS - DF-2                               *-10494.4             3009.19
ALS - FT-100                              164.083              3009.19
CA - DF-2                                *-8899.49             3216.96
CA - FT-100                               1759.01              3216.96
DF-2 - FT-100                            *10658.5              3216.96
---------------------------------------------------------------------------
* denotes a statistically significant difference.
```

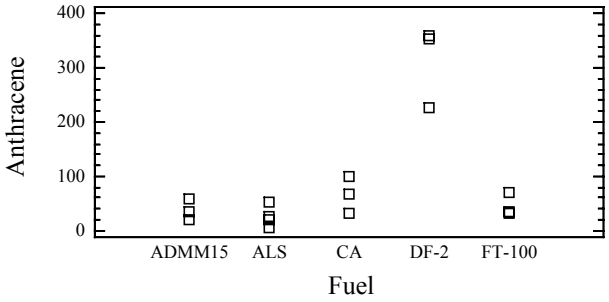
Multifactor ANOVA - Anthracene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: anthr
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



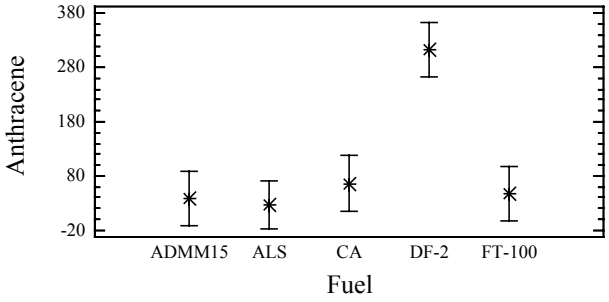
Analysis of Variance for anthr - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	180940.0	4	45234.9	30.26	0.0000
RESIDUAL	16443.1	11	1494.83		
TOTAL (CORRECTED)	197383.0	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average anthracene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The average anthracene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for anthr by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ALS	4	25.7452	X
ADMM15	3	37.8165	X
FT-100	3	46.7152	X
CA	3	66.3094	X
DF-2	3	312.962	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	12.0713	95.5861
ADMM15 - CA	-28.493	102.186
ADMM15 - DF-2	*-275.145	102.186
ADMM15 - FT-100	-8.89873	102.186
ALS - CA	-40.5643	95.5861
ALS - DF-2	*-287.217	95.5861
ALS - FT-100	-20.97	95.5861
CA - DF-2	*-246.652	102.186
CA - FT-100	19.5943	102.186
DF-2 - FT-100	*266.247	102.186

* denotes a statistically significant difference.

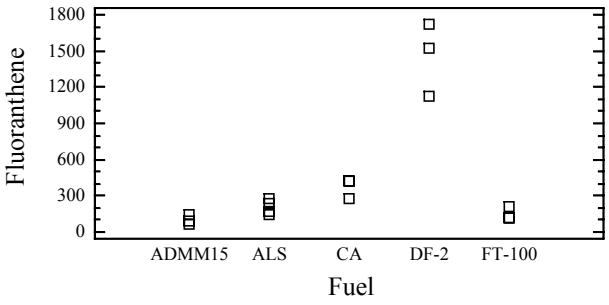
Multifactor ANOVA - Fluoranthene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: fluoran
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



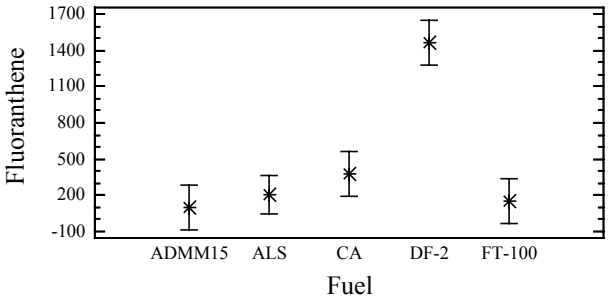
Analysis of Variance for fluoran - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	3.96106E6	4	990264.0	50.53	0.0000
RESIDUAL	215558.0	11	19596.2		
TOTAL (CORRECTED)	4.17661E6	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average fluoranthene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for fluoran by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	98.2249	X
FT-100	3	144.586	X
ALS	4	205.029	X
CA	3	375.497	X
DF-2	3	1459.07	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-106.804	346.086
ADMM15 - CA	-277.272	369.982
ADMM15 - DF-2	*-1360.84	369.982
ADMM15 - FT-100	-46.3612	369.982
ALS - CA	-170.468	346.086
ALS - DF-2	*-1254.04	346.086
ALS - FT-100	60.4428	346.086
CA - DF-2	*-1083.57	369.982
CA - FT-100	230.911	369.982
DF-2 - FT-100	*1314.48	369.982

* denotes a statistically significant difference.

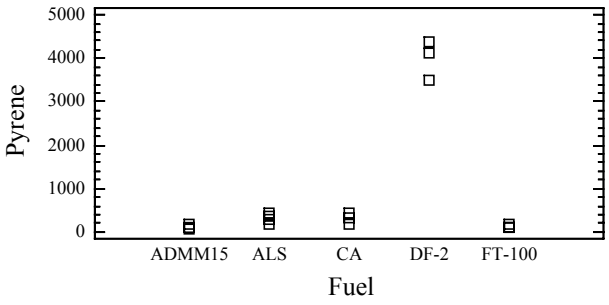
Multifactor ANOVA - Pyrene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: pyrene
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



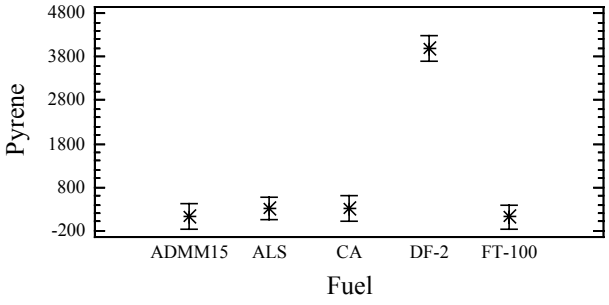
Analysis of Variance for pyrene - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	3.49509E7	4	8.73773E6	185.73	0.0000
RESIDUAL	517496.0	11	47045.1		
TOTAL (CORRECTED)	3.54684E7	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average pyrene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The average pyrene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for pyrene by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
FT-100	3	112.589	X
ADMM15	3	122.261	X
ALS	4	306.989	X
CA	3	317.881	X
DF-2	3	4002.05	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-184.728	536.236
ADMM15 - CA	-195.62	573.26
ADMM15 - DF-2	*-3879.79	573.26
ADMM15 - FT-100	9.67186	573.26
ALS - CA	-10.8921	536.236
ALS - DF-2	*-3695.06	536.236
ALS - FT-100	194.4	536.236
CA - DF-2	*-3684.17	573.26
CA - FT-100	205.292	573.26
DF-2 - FT-100	*3889.46	573.26

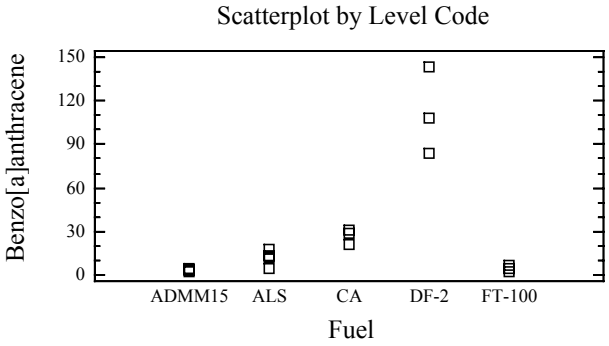
* denotes a statistically significant difference.

Multifactor ANOVA - Benzo[a]anthracene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: benzoaan
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

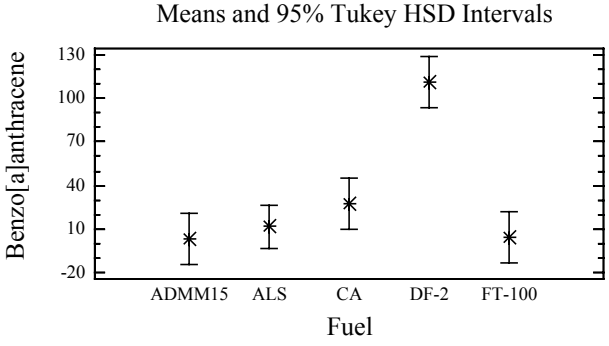


Analysis of Variance for benzoaan - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	25507.2	4	6376.8	35.98	0.0000
RESIDUAL	1949.28	11	177.207		
TOTAL (CORRECTED)	27456.5	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[a]anthracene among the fuels.



CONCLUSION: The average benzo[a]anthracene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[a]anthracene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for benzoaan by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	2.81296	X
FT-100	3	4.49021	X
ALS	4	11.4693	X
CA	3	26.9346	X
DF-2	3	111.52	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-8.65633	32.9109
ADMM15 - CA	-24.1216	35.1832
ADMM15 - DF-2	*-108.707	35.1832
ADMM15 - FT-100	-1.67725	35.1832
ALS - CA	-15.4653	32.9109
ALS - DF-2	*-100.05	32.9109
ALS - FT-100	6.97908	32.9109
CA - DF-2	*-84.5852	35.1832
CA - FT-100	22.4444	35.1832
DF-2 - FT-100	*107.03	35.1832

* denotes a statistically significant difference.

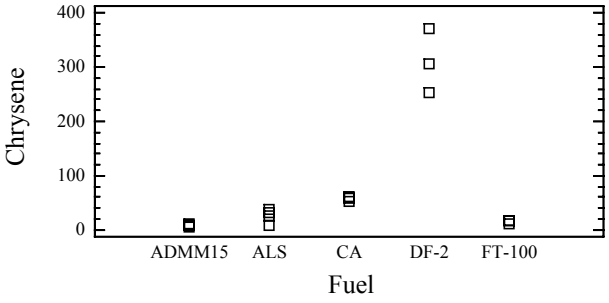
Multifactor ANOVA - Chrysene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: chrysene
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



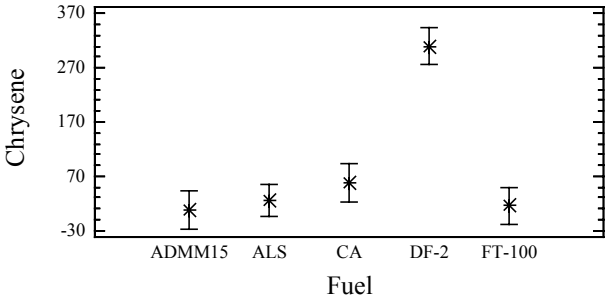
Analysis of Variance for chrysene - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	200207.0	4	50051.8	70.98	0.0000
RESIDUAL	7756.57	11	705.143		
TOTAL (CORRECTED)	207964.0	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically signficant differences in the average chrysene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average chrysene for the DF-2 fuel is significantly different than the remaining four fuels. The average chrysene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for chrysene by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	8.13341	X
FT-100	3	15.3873	X
ALS	4	25.5521	X
CA	3	57.3427	X
DF-2	3	310.066	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-17.4186	65.6504
ADMM15 - CA	-49.2093	70.1832
ADMM15 - DF-2	*-301.933	70.1832
ADMM15 - FT-100	-7.25384	70.1832
ALS - CA	-31.7906	65.6504
ALS - DF-2	*-284.514	65.6504
ALS - FT-100	10.1648	65.6504
CA - DF-2	*-252.724	70.1832
CA - FT-100	41.9554	70.1832
DF-2 - FT-100	*294.679	70.1832

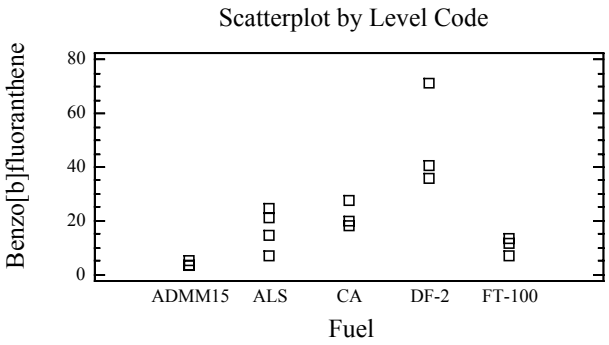
* denotes a statistically significant difference.

Multifactor ANOVA - Benzo[b]fluoranthene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: benzobfl
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

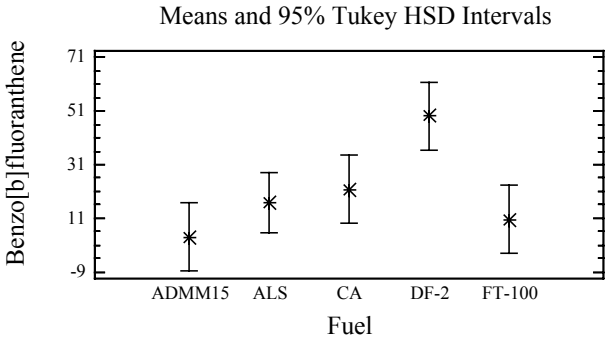


Analysis of Variance for benzobfl - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	3639.5	4	909.874	9.84	0.0012
RESIDUAL	1017.54	11	92.5037		
TOTAL (CORRECTED)	4657.04	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[b]fluoranthene among the fuels.



CONCLUSION: The average benzo[b]fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[b]fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for benzobfl by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	4.11655	X
FT-100	3	10.4925	X
ALS	4	16.872	X
CA	3	21.7637	X
DF-2	3	49.2356	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-12.7554	23.7781
ADMM15 - CA	-17.6472	25.4199
ADMM15 - DF-2	*-45.119	25.4199
ADMM15 - FT-100	-6.37593	25.4199
ALS - CA	-4.89179	23.7781
ALS - DF-2	*-32.3636	23.7781
ALS - FT-100	6.37947	23.7781
CA - DF-2	*-27.4718	25.4199
CA - FT-100	11.2713	25.4199
DF-2 - FT-100	*38.7431	25.4199

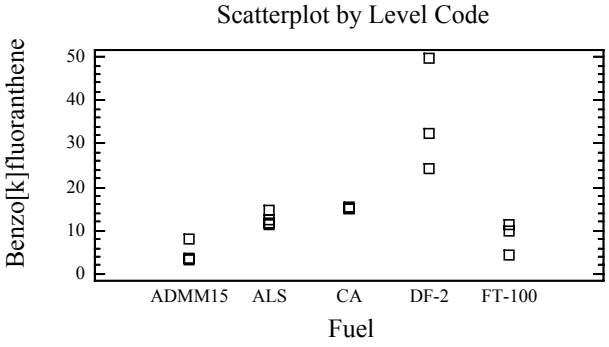
* denotes a statistically significant difference.

Multifactor ANOVA - Benzo[k]fluoranthene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: benzokfl
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

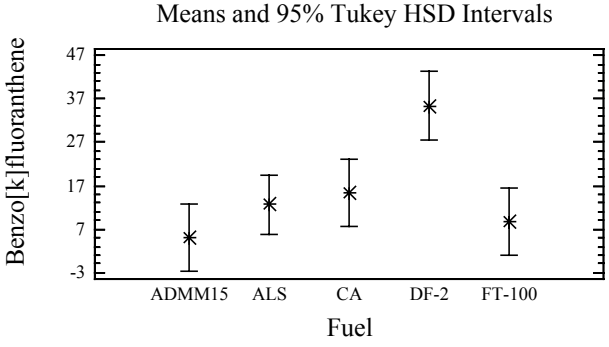


Analysis of Variance for benzokfl - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1697.42	4	424.355	12.26	0.0005
RESIDUAL	380.707	11	34.6097		
TOTAL (CORRECTED)	2078.13	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[k]fluoranthene among the fuels.



CONCLUSION: The average benzo[k]fluoranthene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[k]fluoranthene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for benzokfl by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	5.01499	X
FT-100	3	8.63606	X
ALS	4	12.614	X
CA	3	15.2594	X
DF-2	3	35.4502	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-7.59898	14.5445
ADMM15 - CA	-10.2444	15.5487
ADMM15 - DF-2	*-30.4352	15.5487
ADMM15 - FT-100	-3.62108	15.5487
ALS - CA	-2.6454	14.5445
ALS - DF-2	*-22.8362	14.5445
ALS - FT-100	3.9779	14.5445
CA - DF-2	*-20.1908	15.5487
CA - FT-100	6.6233	15.5487
DF-2 - FT-100	*26.8141	15.5487

* denotes a statistically significant difference.

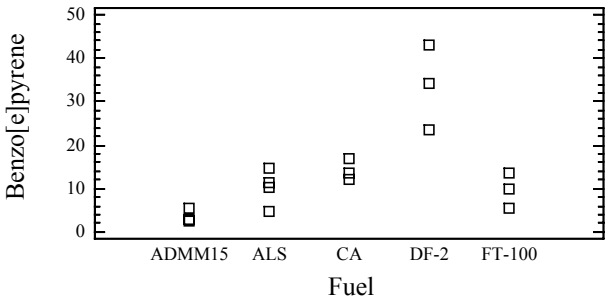
Multifactor ANOVA - Benzo[e]pyrene (µg/kW-hr) Soluble PAH
LPP Only Mode 12

Analysis Summary

Dependent variable: benzoepy
Factors:
fuel
Selection variable: mode=12

Number of complete cases: 16

Scatterplot by Level Code



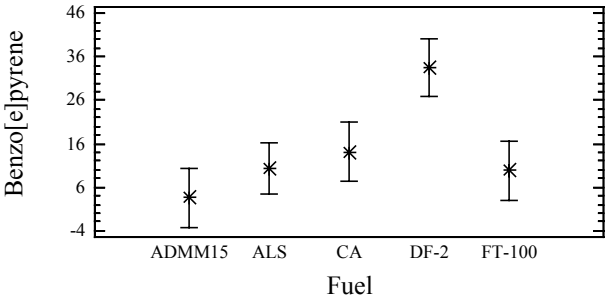
Analysis of Variance for benzoepy - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:fuel	1581.98	4	395.494	14.93	0.0002
RESIDUAL	291.333	11	26.4848		
TOTAL (CORRECTED)	1873.31	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average benzo[e]pyrene among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: The average benzo[e]pyrene for the DF-2 fuel is significantly different than the remaining four fuels. The average benzo[e]pyrene for the ADMM15, ALS, CA, and FT-100 fuels are not significantly different from one another.

Multiple Range Tests for benzoepy by fuel

Method: 95.0 percent Tukey HSD

fuel	Count	LS Mean	Homogeneous Groups
ADMM15	3	3.53663	X
FT-100	3	9.77367	X
ALS	4	10.2791	X
CA	3	14.118	X
DF-2	3	33.5322	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-6.74243	12.7232
ADMM15 - CA	-10.5813	13.6017
ADMM15 - DF-2	*-29.9956	13.6017
ADMM15 - FT-100	-6.23704	13.6017
ALS - CA	-3.83891	12.7232
ALS - DF-2	*-23.2531	12.7232
ALS - FT-100	0.505398	12.7232
CA - DF-2	*-19.4142	13.6017
CA - FT-100	4.34431	13.6017
DF-2 - FT-100	*23.7585	13.6017

* denotes a statistically significant difference.